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The front cover shows part of the experimental steelmaking shop of the United Steel Companies' Research and Development Department, Rotherham. The subject is the 56-lb. vacuum melting furnace.

Classified Advertisements, after page 388

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MAIN ARTICLES

Nomographic Design of Vacuum Installations *by Thea Roth and Ing. A. Roth* 392
Etude nomographique des installations à vide
Fluchtlinientafeln für Vakuumanlagen
Номографический расчет вакуумных установок

Physical Chemistry of Vacuum Treatment of Molten Metals *by R. G. Ward, M.A., Ph.D.* 401
Chimie physique du traitement par le vide des métaux en fuison
Die Physikalchemie der Vakuumbehandlung von geschmolzenen Metallen
Физическая химия вакуумной обработки расплавленных металлов

Pressure Gasification at Morwell *by R. S. Andrews, C.M.G., D.Sc., M.I.Chem.E., F.Inst.F.* 404
Gazéification sous pression à Morwell
Druckvergasung in Morwell
Газификация под давлением в Моруэлл

The Chemical Plant Contractor and the Manufacturer—Part 3 *by M. Davidmann, B.Sc.* 409
L'entrepreneur de construction d'usines de produits chimiques et le fabricant — 3e partie
Der Chemieanlagenbauer und der Fabrikant — Teil 3
Строитель химических установок и фабрикант — Часть 3

Crystallisation of Water by Unidirectional Cooling *by Prof. P. M. Heertjes and Dr. Ir. Ong Tjing Gie* 413
Cristallisation de l'eau par refroidissement unidirectionnel
Kristallisierung von Wasser durch gleichgerichtete Kühlung
Кристаллизация воды путем одностороннего охлаждения

Filtration of the Gaseous Effluent of an Air-cooled Reactor
by I. A. Mossop, B.Sc. Tech. (Manchester) A.M.I.E.E. 420
Filtrage de l'effluent gazeux d'un réacteur à refroidissement par air
Die Filtrierung der gasförmigen Abflüsse luftgekühlter Reaktoren
Фильтрация газового стока реактора охлаждаемого воздухом

OTHER FEATURES

Leader: Distillation Symposium 391
Ceramic Filters for Acid Mist 400
Chemical Process Hazards Symposium 428
American Letter: Increasing Scope of Fluidisation 436
Nomogram: Calculation of Pipe Lagging Thickness taking Dew Point into Account 438
Some Recent Chemical Engineering Theses 442

REGULAR FEATURES

Digest 381
Process Engineers' Notebook 440
Book Reviews 444
Plant Equipment News 446
World of Chemical Engineering 458

Résumés

B.C.E., 5, 6, 392. U.D.C. No. 66-982:531.788

ÉTUDE NOMOGRAPHIQUE DES INSTALLATIONS À VIDE

par T. Roth et A. Roth

Les auteurs présentent une série de nomogrammes pour le calcul rapide des conductances et des dimensions de l'équipement utilisé dans les installations à vide. Ils fournissent des diagrammes applicables aux régimes d'écoulement moléculaire, visqueux et intermédiaire.

B.C.E., 5, 6, 401. U.D.C. No. 669-154.4:541.1.034

CHIMIE PHYSIQUE DU TRAITEMENT PAR LE VIDE DES MÉTAUX EN FUSION

par R. G. Ward

L'article examine l'effet, sur l'équilibre, du traitement par le vide, en se basant sur les courbes d'énergie libre. Il en étudie également l'influence sur la vitesse de réaction. Il conclut qu'il est souvent possible, en se basant sur des considérations thermodynamiques, de prévoir l'état d'équilibre, mais les facteurs physiques qui gouvernent la vitesse à laquelle l'équilibre est obtenu sont aussi importants dans la détermination de l'état du métal en fusion après un certain temps de traitement par le vide.

B.C.E., 5, 6, 404. U.D.C. No. 662.747 (945).

GAZÉIFICATION SOUS PRESSION À MORWELL

par R. S. Andrews

Après avoir noté l'importance des réserves australiennes en lignite, l'auteur s'occupe des problèmes de génie chimique qui se posent à l'usine Lurgi de gazéification sous forte pression, à Morwell, Victoria, Australie. Les deux principaux problèmes ont consisté à redessiner la grille pour l'adapter aux caractéristiques spéciales de la cendre de lignite et combattre la corrosion. L'article considère également la possibilité de produire du carburant liquide synthétique à partir des gaz obtenus.

B.C.E., 5, 6, 409. U.D.C. No. 66.013:658.22.003.2.

L'ENTREPRENEUR DE CONSTRUCTION D'USINES DE PRODUITS CHIMIQUES ET LE FABRICANT—3e PARTIE

par M. Davidmann

Après avoir examiné divers types de relations qui peuvent exister entre le fabricant et l'entrepreneur durant la construction d'une usine, l'auteur suggère que les organismes représentatifs de l'industrie chimique devraient établir un code de conduite.

B.C.E., 5, 6, 413. U.D.C. No. 536.2:541.123.1.

CRISTALLISATION DE L'EAU PAR REFROIDISSEMENT UNIDIRECTIONNEL

par P. M. Heertjes et Ong Tjing Gie

L'article est une étude sur la cristallisation de l'eau par refroidissement unidirectionnel. Lorsque le liquide est au point de fusion, il existe un rapport linéaire entre le carré de l'épaisseur de la couche des cristaux qui s'est formée et le temps théoriquement requis. La même constatation peut être faite lorsque le liquide est à une température au-dessus de son point de fusion, si l'on s'assure que le transport de chaleur à travers le liquide ne se fait que par conduction.

On peut distinguer des zones de conduction et de convection pour les courants de chaleur montante pour les liquides ayant des températures supérieures à 4° C. Le coefficient partiel du transport de chaleur par convection libre a été déterminé et corrélé avec le numéro de Grashof et Prandtl.

B.C.E., 5, 6, 420. U.D.C. No. 66.074.2:621.039.58

FILTRAGE DE L'EFFLUENT GAZEUX D'UN RÉACTEUR À REFROIDISSEMENT PAR AIR

par I. A. Messop

L'élimination des matières solides particulaires des effluents d'un réacteur refroidi par air cause de nombreux problèmes que l'on ne trouve pas dans les exploitations industrielles normales. L'article souligne ces restrictions et conditions et décrit la mise au point d'un filtre qui convient très bien à cette application.

Kurzreferate

B.C.E., 5, 6, 392. U.D.C. No. 66-982:531.788

FLUCHTLINIENTAFELN FÜR VAKUUMANLAGEN

von T. Roth und A. Roth

Der Artikel bringt eine Reihe von Rechentafeln zur schnellen Berechnung der Leitwerte und Abmessungen von Einrichtungen für Vakuumanlagen. Die Tafeln eignen sich für molekuläre, viskose und intermediäre Flussbetriebsbedingungen.

B.C.E., 5, 6, 401. U.D.C. No. 669-154.4:541.1.034

DIE PHYSIKALCHEMIE DER VAKUUMBEHANDLUNG VON GESCHMOLZENEN METALLEN

von R. G. Ward

Der Autor bespricht die Einflüsse der Vakuumbehandlung auf das Gleichgewicht mit Hinsicht auf die freien Energiekurven. Der Einfluss der Reaktionsgeschwindigkeit wird ebenfalls berücksichtigt. Er gelangt zum Schluss, dass thermodynamische Einflüsse es oft gestatten, das endgültige Gleichgewicht vorherzusagen, dass jedoch die physikalischen Faktoren, welche die Annäherungsgeschwindigkeit an das Gleichgewicht bestimmen, ebenso wichtig sind, um den Zustand der Vakuumschmelze nach einer bestimmten Vakuumbehandlungszeit zu bestimmen.

B.C.E., 5, 6, 404. U.D.C. No. 662.747 (945).

DRUCKVERGASUNG IN MORWELL

von R. S. Andrews

Nach einer Besprechung der Australischen Kohlereserven, befasst sich der Autor mit den chemischen Problemen einer Lurgi-Hochdruckvergasungsanlage in Morwell, Victoria, Australien. Die beiden Hauptprobleme waren die Neukonstruktion des Rosts für Braunkohleasche und Korrosionsverhütung. Der Artikel bespricht auch die Möglichkeiten der Erzeugung eines synthetischen flüssigen Brennstoffs aus den verfügbaren Gasen.

B.C.E., 5, 6, 409. U.D.C. No. 66.013:658.22.003.2.

DER CHEMIEANLAGENBAUER UND DER FABRIKANT—TEIL 3

von M. Davidmann

Nach einer Besprechung der möglichen Arten der Zusammenarbeit zwischen Fabrikant und Anlagenbauer während des Baues der Anlage . . . schlägt der Verfasser einen Vehraltungs Kodex massgebenden Körperschaften der Chemie-Industrie vor.

B.C.E., 5, 6, 413. U.D.C. No. 536.2:541.123.1.

KRISTALLISIERUNG VON WASSER DURCH GLEICHGERICHTETE KÜHLUNG

von P. M. Heertjes und Ong Tjing Gie

Die Verfasser besprechen die Wasserkristallisierung durch gleichgerichtete Kühlung. Für den Schmelzpunkt fanden sie einen linearen Zusammenhang zwischen dem Quadrat der Dicke der gebildeten Kristallschicht und der theoretisch benötigten Zeit. Dasselbe lässt sich auch für die Flüssigkeit über dem Schmelzpunkt beweisen, wenn die Bedingungen so gewählt werden, dass die Wärmeleitung durch die Flüssigkeit nur durch Konvektion erfolgt.

Für die Aufwärtsströmung der Wärme bei Flüssigkeiten bei mehr als 4° C können Konduktions- und Konvektionszonen unterschieden werden. Der Wärmeübertragungskoeffizient für freie Konvektion wurde berechnet und mit der Grashof und Prandtl'schen Zahl in Übereinstimmung gebracht.

B.C.E., 5, 6, 420. U.D.C. No. 66.074.2:621.039.58

DIE FILTRIERUNG DER GASFÖRMIGEN ABFLÜSSE LUFTGEKÜHLTER REAKTOREN

von I. A. Messop

Die Filtrierung von festen Partikel aus dem Abfluss eines luftgekühlten Reaktors stellt eine Reihe von Problemen, denen man bei normalen industriellen Anwendungszwecken nicht begegnet. Der Artikel bespricht die Arbeitsbedingungen und beschreibt die Entwicklung eines Filters, welcher für diesen Zweck besonders geeignet ist.

Резюме

B.C.E., 5, 6, 392. U.D.C. No. 66-982:531.788

НОМОГРАФИЧЕСКЫЙ РАСЧЕТ ВАКУУМНЫХ УСТАНОВОК

Т. Рот и А. Рот.

Приводится серия номограмм для быстрого вычисления активной проводимости и размеров оборудования употребляемых в вакуумных установках. Приведенные диаграммы применимы при молекулярном, вязком и промежуточном течении.

B.C.E., 5, 6, 401. U.D.C. No. 669-154.4:541.1.034

ФИЗИЧЕСКАЯ ХИМИЯ ВАКУУМНОЙ ОБРАБОТКИ РАСПЛАВЛЕННЫХ МЕТАЛЛОВ

Р. Г. Уорд.

Обсуждается эффект вакуумной обработки на устойчивое равновесие в связи с графиком свободной энергии. Рассматривается также влияние на степень реакции. Автор статьи приходит к заключению, что термо-динамические соображения часто дают возможность предсказать окончательную степень устойчивого равновесия, но физические факторы регулирующие степень подхода к устойчивому равновесию одинаково важны при учете степени вакуумного сплава после определенного времени вакуумной обработки.

B.C.E., 5, 6, 404. U.D.C. No. 662.747 (945).

ГАЗИФИКАЦИЯ ПОД ДАВЛЕНИЕМ В МОРУЭЛЛ

Р. А. Андрюс.

Отметив размеры угольных запасов в Австралии, автор статьи расматривает проблемы химической технологии на заводе Моруэлл в провинции Виктория в Австралии, где применяется газификация под высоким давлением по процессу «ЛУРГИ». Двумя главными проблемами были — реконструкция решетки в виду особых свойств зоны бурого угля и предотвращение коррозии. В статье расматриваются также возможности выработки синтетического жидкого горючего из добытых газов.

B.C.E., 5, 6, 409. U.D.C. No. 66.013:658.22.003.2.

СТРОИТЕЛЬ ХИМИЧЕСКИХ УСТАНОВОК И ФАБРИКАНТ — ЧАСТЬ 3

М. Давидманн.

Расмотрев различные виды отношений между строителем и фабрикантами во время постройки химической установки, автор статьи предлагает, что-бы организации представленные в химической промышленности, выработали надлежащий кодекс поведения.

B.C.E., 5, 6, 413. U.D.C. No. 536.2:541.123.1.

КРИСТАЛЛИЗАЦИЯ ВОДЫ ПУТЕМ ОДНОСТОРОННЕГО ОХЛАЖДЕНИЯ

Р. М. Хертьес и Онг Тьинг Ги.

Подвергаясь изучению кристаллизация воды путем одностороннего охлаждения. Для жидкости при температуре на точке плавления, авторы обнаружили линейное соотношение между квадратом толщины слоя кристалла и временем требуемым в теории. Тоже самое можно иллюстрировать в отношении жидкости при температуре выше точки плавления, в таких условиях, когда тепло проходит через жидкость только путем проводимости.

При прохождении тепла вверх через жидкости при температурах выше 4-х гр по Цельсию, возможно различить зоны проводимости и конвекции. Установлен частичный коэффициент для передачи тепла путем свободной конвекции и установлено его соотношение с числом Грасгоф и Прандтл.

B.C.E., 5, 6, 420. U.D.C. No. 66.074.2:621.039.58

ФИЛЬТРАЦИЯ ГАЗОВОГО СТОКА РЕАКТОРА ОХЛАЖДАЕМОГО ВОЗДУХОМ

И. А. Моссоп.

Удаление твердых частиц из стока реактора охлаждаемого воздухом ставит много проблем, которые не встречаются в нормальной промышленной практике. Статья перечисляет также ограничения и условия и описывает развитие наиболее подходящего для этого фильтра.

DIGEST OF INDUSTRIAL AND TECHNICAL DEVELOPMENTS

Who wants Free Advice on Instrumenting a Plant?

SURPRISINGLY, there has been no firm response to a generous and interesting offer by the Instrumentation Advisory Committee of the Association of British Chemical Manufacturers. In 1956, at a conference held in Harrogate, this statement was made by the Chairman of the Committee at that time, MR. A. J. YOUNG of Imperial Chemical Industries Ltd.

"My suggestion is that any member who is really interested in this subject and who really feels that there is profit to be made by the better application of instruments in his own plant should send in to the A.B.C.M. Instrumentation Advisory Committee a short statement on a plant which he thinks suitable for study by the Committee. If a number of members send in such statements, the Advisory Committee will select one plant and make a very careful case study of that plant. It will, in conjunction with the makers and contractors, and other organisations involved, produce a plan for the instrumentation of the selected plant and an economic statement which will show the managing director of the Company what profit can be expected from the proposed instrumentation. One obligation is attached to this offer; namely, that if the Committee's proposals are implemented (as they naturally would be if the economic case were good enough), then the Company concerned must allow publication of the case study and of the results achieved subsequently by the recommended instrumentation."

In the Association's Productivity News No. 37, they have reiterated this offer adding that the firm's name would not be mentioned when the study was published. Unlike the situation for other guinea pigs, here the test subject and others would both clearly gain.

Assessing Toxic Hazards

SETTLING the safe limits for concentrations of dangerous gases, vapours, dusts and fumes in air has its own occupational hazards. Grim experience sometimes shows that it is better to lower a figure previously thought to be safe. The latest of the Safety, Health and Welfare booklets of the Ministry of Labour (New Series No. 8)* which quotes information of this kind for toxic substances in factory atmospheres opens with a more general discussion. After noting that the first step must be to know what are the substances used in a process and the possible hazard, the authors go on to discuss methods of dealing with potential dangers. The best solution, of course, is for there to be no toxic dust or fume and for a harmless substance to be used instead—or at least a less harmful one. This should always be the first possibility to be explored. If substitution proves to be impracticable, the next best protection is to prevent the escape of injurious dust or fume into the atmosphere of any workroom. This can be ensured by totally enclosing the process or plant, preferably at a slightly reduced pressure. The next step is to consider adopting the principle of the "fume cupboard." The material is placed in an enclosure and the worker remains outside. Local exhaust systems or personal protective equipment are last resorts.

The maximum permissible concentrations listed are based on those formulated by the Committee on Threshold Limits of the American Conference of Governmental Industrial Hygienists, and also used by the International Labour Office for papers published in its Model Code of Safety Regulations. The figures relate to average concentrations for a normal working day and are subject to annual review. We understand that they are lower than those applied in some British firms. With them is a very short list of references to methods of detection. The value of the booklet would be greatly enhanced if guidance were offered on how to use the information. One simple addition that alone would greatly ease the path of the user would be to give against each substance named a reference to an analytical method for determining it—perhaps with a special mark to indicate if the method had received some kind of official approval.

*H.M.S.O. 1960. 1s.

Technological Use of Radiation

AT the conference on applied radiation in the University of New South Wales, Australia, the term "technological" in the title has been widely interpreted. It includes studies of chemical dosimetry and attempts to improve biological plants as well as more obvious subjects. A statement presented by the U.S. Atomic Energy Commission on the rationale of its work in these fields is very interesting, for its experience has confirmed the frustrations of empirical trials and the value of attention to fundamentals. The paper—presented by D. M. RICHMAN and P. C. AEBERSOLD—points out that only a few "break-throughs" of great commercial significance have occurred as a result of the pragmatic approach. Consequently, ionising radiation has not yet become a major source of process energy for the chemical and other industries. It is, therefore, the objective of the Commission to bridge the wide gap that exists between basic radiation chemistry research performed mainly by universities and national laboratories, and highly applied research on products of commercial value performed mainly by private industry. Bridging this gap requires efforts in two major areas, one concerned with radiation chemistry and called "process radiation research," the other related to source and irradiator development and called "radiation engineering." The latter branch of engineering is aimed at learning how to use large sources of ionising radiation safely, effectively and efficiently. It includes development of new and improved techniques for large source production, handling, fabrication and encapsulation and development of radiation as an engineering unit operation similar to other energy transfer processes. Process radiation research—the main subject of the paper—is concerned with basic and applied radiation chemistry. It is aimed at finding commercial applications for ionising radiation.

Specific technical problems include lack of knowledge and understanding of ion-molecule reaction mechanisms, energy transfer mechanisms and the effect of the structure of molecules on radiation chemistry reaction mechanisms.

To conclude the story are specific studies of the possibilities of using ionising radiation for making phenol, aniline, fluorinated aromatic hydrocarbons, ethylene glycol, hydrazine and acetylene.

Mobile Process-dynamics Analyser

IS it possible to examine the dynamic behaviour of commercial plants without interfering with production? Illustrating his methods by results of tests on an ethylene-ethane splitting column O. RADEMAKER has recently reported the use of a process-dynamics analyser which can obtain a wealth of information under these conditions. Representing a new version of a previously described unit it consists essentially of three parts: these are the disturbance generator, the detecting elements, and the recording equipment, built into a single mobile unit. At the Distillation Symposium of the Institution of Chemical Engineers PROF. RADEMAKER showed how the disturbance generator superimposes its disturbance upon the pneumatic signal from a controller to its control valve. Thus it is possible to carry out experiments while the controller is in operation. This is a great advantage if the process itself is unstable and the average conditions must be strictly maintained. The generator can produce adjustable sine waves and step changes; constant-rate disturbances can be approximated by the flanks of a sine wave. A number of detecting elements are available dependent on the variable which is being investigated. For differential pressure, the element is based on a bellows driving a strain gauge bridge, while for absolute pressure a Taylor "Transaire" transmitter is used. Temperature is detected by thermocouples or platinum resistance elements and valve stem displacement by an element operating a potentiometer in a wheatstone bridge. Like the recorders, all detecting elements have been trimmed so that any recorder can be used with any element without individual adjustment or calibration. Finally the recording equipment consists of two 3-channel recorders and associated preamplifiers. The number of channels can be doubled by duplexing; each recorder is then switched back and forth between two inputs twenty times in each complete sinusoidal period. This programme was initiated to provide a sound basis for examining the performance of automatic control systems.

Designing Heat Exchangers

HOW do you set about selecting the right heat exchanger for a particular duty? Often, custom plays a considerable part but for those who wish to attempt a wider approach the latest* of the Dechema-Erfahrungsaustausch series will be very valuable. In addition to listing types of exchangers, with notes of their recommended uses, the booklet sets out a selection table. This gives nine possible combinations of six sets of heat transfer conditions. Possible changes of condition are cooling a gas, heating a gas, cooling a liquid, heating a liquid, condensing a vapour, boiling a liquid. Each of these is considered for high, medium and low temperature and typical examples given of the various cases. In the table the types of exchanger are then noted as suitable or otherwise for a particular duty. Following this useful guide, are the physical fundamentals of the subject—basic equations, conduction, convection, radiation and pressure loss—and then design calculations. There are sample calculations, a glossary of German terms with Anglo-American equivalents and a list of references. Units are of course metric.

In Britain we understand that the relevant British Standard, namely 2041: 1953, has now been revised and is due to be published. However this specification is restricted to tubular heat exchangers and—unlike the T.E.M.A. Standard on which it is largely based—gives only dimensions, materials and similar mechanical requirements without discussing thermal design. Its scope is therefore different from that of the German publication which is essentially a design manual giving, as its necessary complement, a list of the appropriate DIN standards for concepts, symbols, constructional elements, types of construction and performance tests.

*"Wärmeaustauscher," by H. Kühne Dechema, Frankfurt-am-Main, 1960. DM 43.60 non-members; DM 34.90 Dechema members; plus postage.

Scholarships to Encourage Research in Chemical Engineering

A UNIQUE feature of the two scholarships announced by the Institution of Chemical Engineers is that they are tenable at *any* educational institution in the United Kingdom in receipt of grants from the University Grants Committee, and having a department of chemical engineering under the direction of a professor of chemical engineering. The funds are provided by Constructors John Brown Ltd. The only other scholarship funds with which the Institution is directly connected are those for the Ure Bursary, but these are available only at Imperial College. There are two CJB Scholarships—each normally tenable for a period of two years. Maximum value of each scholarship is £500 per annum, and they are open to candidates holding a qualification recognised by the Institution which exempts from all parts of its Examination. Applications should reach the Institution not later than Wednesday, 1st June 1960.

"Polishing" Drinking Water More Cheaply

TO economise in capital and in cost of coagulant, the Water Examination Department of the Metropolitan Water Board has been considering methods of clarifying stored River Thames water with coagulants without passing it through a clarifying basin before filtration. However, the greater part of the matter to be removed consists of algae not silt. These organisms are not easily retained in the floc of coagulants. A trial was therefore carried out in which the aim was to remove as much of the algae as possible by micro-straining through fabric-covered rotating cylinders rather like reversed rotary filters—the water passing outwards. The filter fabric had a limiting aperture of 35 microns. Solids are removed from this fabric by closely spaced jets of water on the outside washing the solids into an internal trough discharging to waste. Subsequent treatment was based on adding aluminium sulphate solution adjusted with sulphuric acid to *pH* of 7.4 and in some trials a suspension of silica activated with sodium bicarbonate.

Eventually only 10 mg/l. of aluminium sulphate and 11 mg/l. of sulphuric acid were added to the strained water which was filtered on Candy or Paterson rapid gravity sand filters at rates up to 100 gal/sq. ft hr. As the culminating point of a year's work, this trial was made for 11 weeks and overall results were encouraging compared with those of a normal dual filtration plant. DR. E. WINDLE TAYLOR, the Board's Director of Water

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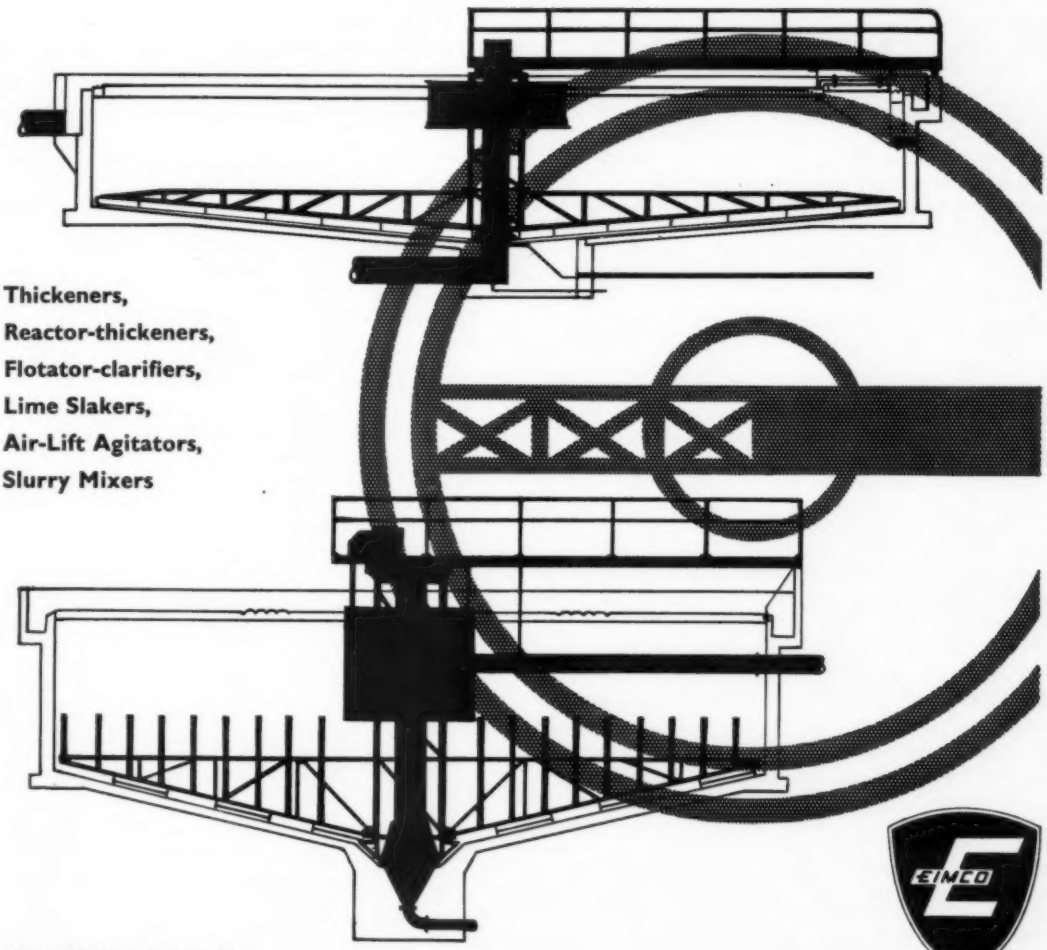

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P.2699

Examination, includes an account of this work in the recently published 38th report of the department which covers the years 1957-58. We understand that no more work has been carried out on the project although it is intended to pursue this line of work further.

Centralised Water Treatment for Cooling Towers

IS it possible to centralise the chemical feed of acid and inhibitor to a group of cooling towers? An American company has now reported* the results of eight years' experience with this technique. It has provided excellent corrosion control at a low labour cost—estimated at one man-hour per day for a set of five cooling systems, using a total of 155,000 gal. of water a day. Raw water passes through a high alloy pipe where the acid is added, then to a mixing chamber. A *p*H sampler is attached to the outlet pipe and the recorder-controller connected to this controls a positive displacement feed pump, with a d.c. variable speed motor, supplying the acid from its storage tank. Finally, inhibitor is added from a chemical tank mixer into this acidulated water which then passes to a final mixer and on to the towers. There is a raw water sampler on the inlet line and a finished water sampler following the final mixer.

Surprisingly the make up line has lasted the whole of the eight years and looks good for several more. The line consists of four-inch uncoated steel pipe. It has been carrying water at *p*H of 4.5 to 5.0 and occasionally lower, with only 8 to 10 ppm of corrosion inhibitor present. The amount of corrosion inhibitor present in the feed line is below its effective range because it is concentrated five to six times in the towers.

Reporting this ingenious yet basically simple system, W. HARRISON and P. G. BIRD set out three requirements for successful operation of a centralised feed system. The first is to obtain reliable feeding equipment for the acid and inhibitor; the second is good control of blowdown from each tower and the third, systematic chemical testing of recirculating water in each tower. The testing is necessary for adjustments in blowdown and correction in chemical feed; it also serves as a check on the automatic *p*H controller. Linked with this, the key to maintaining good chemical testing and control lies in securing co-operation of supervisors and operating personnel by helping them to understand the importance of water control.

**Corrosion*, 1960, Vol. 16, No. 4, p.9.

Inventions Available Under Licence

EVERY six months the National Research Development Corporation publish a review of inventions for industry. Among those set out in the current issue (No. 16) as available under licence is a unit for sea water distillation using the heat pump principle with a refrigerant as the heat transferring fluid. Two advantages are low temperature operation—minimising scaling difficulties—and operation from mechanical power alone. Initial experiments were conducted with a refrigerator compressor driven by electric motor; without any attempt at providing good thermal qualities by insulation, and without precise correlation of areas, it proved possible in 24 min, to produce temperatures of 34°F and 83°F. The efficiency was 28% of gross power or 58% of true work of compression. In the same bulletin there is also a reference to a pipe joint developed for use with highly toxic chemicals. Male and female grooves are formed in inner and outer tubes; to make the joint a sleeve of material between the tubes is deformed by an axial load to fill the grooves and give a locked joint. Other items of interest are further types of pipe joint, a surface-type sludge aerator said to be cheaper than normal brush aerators and heat exchangers. There are in addition several instruments including developments in ultrasonic flaw detectors.

Expenditure on Research

IN 1958 as in 1955 the chemical industry represented one of the main concentrations of research and development effort in the country. Its total estimated expenditure was £43 million—most of this being spent in its own establishments—or 5.9% of its "net output." The latter term represents the value added to material by the production process and it is applied to avoid the possibility of double counting if gross production figures are used where intermediates are passing from one unit to another. Overall, British manufacturing industry spent about £300 million on research and development in 1958, compared with about £190 million in 1955. This represents 4.2% of manufacturing industry's contribution to national production compared with 3.1% in 1955.

For all manufacturing industry the cost per qualified worker was nearly £11,000—or excluding aircraft—£8000. This is thought to represent a true increase in expenditure per qualified worker, compared with that in 1955, of about 27% at constant prices. An important factor is the increase in the number of supporting staff per qualified worker from two in 1955 to three in 1958. For chemical and allied trades the cost was £6,655 and for mineral oil refining £9,844.

Piping Liquefied Gases

IN this country liquefied gases are usually transported by insulated container when the distances are greater than a few hundred yards. At Canvey Island where liquid methane is transferred from ship to tank, there is a relatively long pipe-line of just under half a mile. However, the Cryogenic Engineering Laboratory at the National Bureau of Standards, after a study of piping liquefied gas, have reported that they consider this technique feasible for (undefined) "long-distance" transfers. In their view transfer by pipeline can be extended to appreciable distances provided the designer is aware of the limitations in performance introduced by undesirable cool-down characteristics. They consider the design of such a system relatively straightforward; a study, carried out by R. B. JACOBS, provides the theory for designing long-distance pipeline systems for low-temperature operation and also gives information required for numerical computation.

Either pumping systems or a process plant, such as a liquefier, can supply the energy required to force the fluid through the line. If several pumping stations are used the system consists of a series of pipes with the fluid state specified at the inlet and outlet of each pipe. Since it is wasteful to carry unavailable energy (as sensible heat) through the system, intermediate stations along the line should cool the liquid by refrigeration and/or flashing.

These conclusions are based on a mathematical model describing the flow characteristics of the line in terms of the design parameters, flow rate, line length, line diameter, pumping pressure, heat leak, and fluid properties. To check the economic feasibility sources of losses were examined. These were the loss due to energy dissipation in the pump container and cooling prior to line entry;

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flashing caused by heat leak and energy introduced by the preceding pump; cool-down from ambient to operating temperature and trapped-liquid loss from liquid that cannot be removed at the end of the transfer. The proof of this pudding will be seen in the results of experimental checks on long-distance transfer systems. It may be recalled (*British Chemical Engineering* May 1960, p. 309) that MR. HUTCHISON, President of the Institution of Chemical Engineers has also noted how cheap is this method of energy transfer.

Simulating a Large Chemical Plant on an Electronic Analogue Computer

EARLY last year we published an account of the world's largest hydrogen peroxide plant operated by Laporte Industries Ltd. at Warrington (*British Chemical Engineering* 1959, Vol. 4, No. 2, p. 88). Brief mention was made of the use of an analogue computer to simulate aspects of the plant performance. A. H. DOVETON and K. C. W. PEDDER have now filled out some of the details of this programme. In a paper presented to the Society of Instrument Technology and due to be published in its *Transactions* they describe the plant and the computer, showing the way in which the basic knowledge of the plant in engineering terms was treated both mathematically and in circuit design, to build up the analogue. It is believed that this was a pioneering investigation—one of the first simulations of a complete process in this country. The aim was not particularly to solve control or operational problems, except in one important case. It was rather that the analogue should serve as a check on design, and show up any difficulties of operation which might not have been suspected when the design was made. In particular, the authors were interested in the behaviour of the plant during crash shut-downs, and in gaining "experience" of the response of the plant to load changes. Thus their main objectives were a preview of the operational characteristics of the plant, confirmation that the design was adequate for all conditions of operation and foreknowledge of the behaviour of the plant on start-up, load changes, and crash shut-down. They were also seeking confirmation that there would be no untoward interaction between vessels, and that no parts of the plant were particularly sensitive to periodic disturbances such as were of necessity introduced by filter changing. A further objective was to determine optimum controller settings, solve a particular problem of the control of a second reactor/degasser system and finally assess the value and difficulties of analogue simulation. Did the project succeed? The users thought it a very realistic investment of time and money. Moreover a similar investigation today could probably be carried out for about half the cost.

Meeting Radiation Hazards

IN Britain, the Windscale accident sparked off a strong current of public concern about radiation hazards in general. The immediate consequence of the accident was the setting up of the Fleck Committees. Among the recommendations of the one on health and safety was that the Atomic Energy Authority should build up a national supply of specialists in these subjects and establish a national training centre. In turn, therefore, the Authority itself set up a committee, under the chairmanship of SIR DOUGLAS VEALE, to study these problems on a national scale including aspects outside their own control. Wisely this body took their terms of reference to extend beyond surveying the needs for specialist radiological health and safety staff; they also reviewed the need for education and information over a wide field.* What are their views? A national radiological advisory service should be set up but the Authority should not organise a national training centre. Existing and projected university postgraduate courses should be adequate when fully developed to meet estimated demands for graduates for the topmost levels of health and safety staff. Courses should be set up at Colleges of Advanced Technology for the next grade of staff who will have day-to-day managerial responsibilities or be engaged in operational research. For supporting staff without professional qualifications courses at technical college or place of employment should be provided. There are also proposals for background training for administrators, the medical profession and others—even for the use of radio and television to inform the general public. But the Authority itself should not do this general work—the province of existing educational or other establishments—restricting itself to specialised colloquia and conferences.

Another aspect of the question is covered in the current issue of *Atom* by MR. G. R. NEWBERY, Manager of the Physics Department at the Radiochemical Centre, who was concerned with moving isotopes safely. Applying present precautions the hazards were assessed as negligible compared with those of distributing gas, electricity, toxic, inflammable or explosive materials. Meanwhile, attempts to make internationally acceptable regulations for this traffic have occupied the International Atomic Energy Agency and a short review of the work appears in its current Bulletin.

*Training in Radiological Health and Safety. H.M.S.O. 1960, 5s. 6d.

Are there Uses for "Safe" Uranium?

THOUGH it is free from the bogies of political complications, depleted uranium—from which most of the fissile U-235 has been removed—causes its own kind of trouble. The U.S. Atomic Energy Commission has accumulated large stocks of the material and will continue to do so for many years. At its request, Battelle Memorial Institute surveyed potential non-nuclear uses for an assumed 10,000 to 20,000 tons per year. For the immediate future, they concluded, the possibilities were unfavourable. On a longer-term basis however there might be profitable uses because the material has interesting properties and would be available in tonnage quantities. Among the potential markets suggested were for cathodic protection in competition with magnesium or zinc, or as a colouring agent for ceramic glazes and glasses and for chemical uses. Most of the historical uses of uranium in the chemical field have been small but it might be applied in catalysis and inorganic ion-exchange systems. In mineral concentration a uranium compound for a slurry application would be considered in place of a material such as ferrosilicon but the best possibilities of development were thought to be metallurgical. For some applications, such as for high-density metals, special alloys, and high-speed steels, uranium would compete with other high-cost metals. However, most of the potential uses will require research and development and trial on an industrial level perhaps for five years or so before significant markets can be developed.

To round off the subject we might note that if the uranium were returned to nuclear power plants for use in fast breeder reactors and if 10 per cent of the nuclear power generation in the U.S.A. were to be from fast breeder reactors by 1980, the amount of U-238 required as fuel that year would be only about 22.6 tons.

Aluminium: Properties and Fabrication

IT was enterprising of the Northern Aluminium Company Ltd. to organise their own symposium in order to present new information on the use of aluminium for transport and handling of liquefied gases at sub-zero temperatures. MR. R. J. DURHAM described the results of tests on plate, conforming to B.S. 1477: NP5/6M, in

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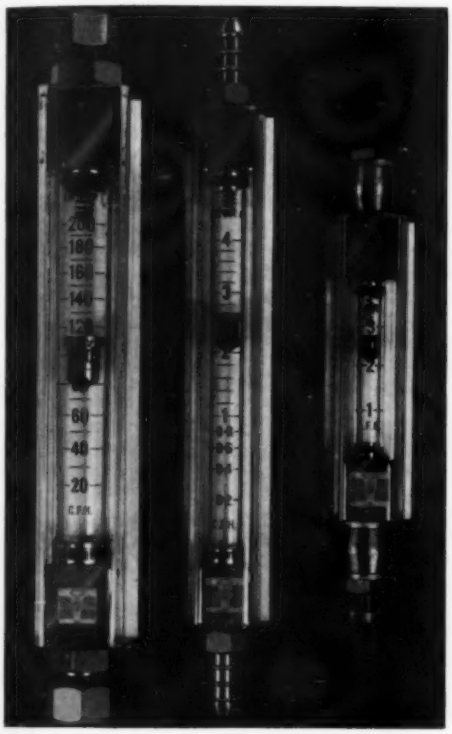

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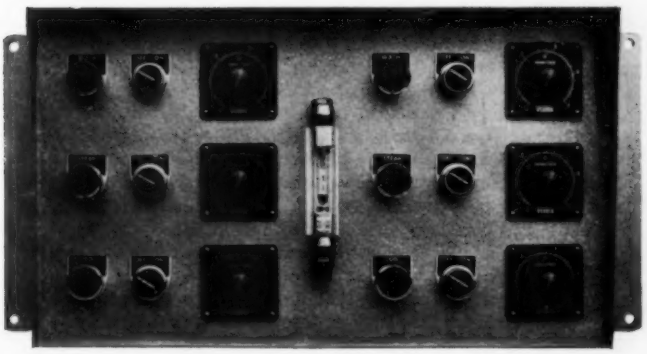

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several thicknesses up to 2 in. This alloy has a nominal composition of 4½% magnesium, ¾% manganese, the remainder being aluminium. The properties of both parent material and pieces joined by butt welding were determined at room temperature and at −196°C. It proved to be suitable for use in welded structures over this temperature range. Tensile ultimate stress and elongation are greater at −196°C than at room temperature. Proof stress is about the same at both temperatures. Young's modulus is increased at −196°C by about 12% over the room temperature value. In reversed bending under zero mean stress, fillet welds at −196°C have fatigue strengths 60 to 70% greater than the corresponding room temperature value for endurances between 100,000 and 5,000,000 cycles. When the Navy tear test and notch tensile tests are carried out, cracking does not take place until extensive yielding of the notched section has occurred. The energy required to propagate the Navy tear crack, once it is formed, is not materially reduced by lowering the temperature.

Suiting the Man to the Job

DURING recent years there has been rising interest in engineering circles in better selection of workers on the one hand, and on the other in design of equipment to suit human capacities. One aspect of this—the effects of ageing on human skill—forms the subject of a new booklet,* one of a series of industrial versions of academic reports. Based on the work of the Nuffield Unit for Research into Problems of Ageing, it presents a number of practical conclusions. For example, where the job demands knowledge, accuracy and stability the older worker compares favourably with the younger man. On the other hand, the older worker may find it difficult to keep up with the demands for speed, whether these are made by the machine he operates, or by the team he works with, or by a payment system. But provided he is not debarred from heavy physical work on medical grounds, the older worker finds its demands less exacting than those made by lighter work involving pressure for speed.

Changes in mental ability that are found as one grows older are more subtle. They reduce a worker's efficiency at jobs where he has to remember information for a short time before he makes use of it, or where he has to translate or alter the information in some way mentally before he can take the appropriate action. With these points as background the research workers have gone on to make a number of suggestions for matching the job and the older worker, and the advice is rounded off sensibly with an acknowledgement of the need for more work and more facts. In view of the trends in the age-structure of most industrial countries, the importance of this work can scarcely be exaggerated.

*"The Older Worker and His Job" by Hilary M. Clay. Problems of Progress in Industry, No. 7. Department of Scientific and Industrial Research. H.M.S.O. 1960. 1s. 3d.

Phase Relations of Hydrogen-Oil Systems

AS a consequence of the extending use of hydro-refining processes there is an increasing demand for data on hydrogen-oil mixtures at higher temperatures and pressures. S. R. C. DRYER of the British Petroleum Co. has recently described a unit designed to be flexible enough to examine phase relationships over a wide range of operating conditions and feedstocks. The basis chosen for design was a continuous flow unit in which hydrogen and oil would be mixed and fed into a small flash chamber capable of operating at temperatures up to 500°C and pressures up to 1000 psig. After attaining equilibrium the two phases would be removed from the high-temperature zone as quickly as possible and metered accurately. Details of the unit meeting these specifications are given in a paper in *J. Inst. Petroleum*, 1960, Vol. 46, No. 434, p. 46. With its aid system conditions were investigated over the range 150 to 1000 psig, 100° to 420°C and 500 to 6000 scf hydrogen per barrel (42 U.S. gallons) of oil. Gasoline, gas oil, crude oil and residual feedstocks were all used.

MR. DRYER found that hydrogen acts mainly as an inert which reduces the partial pressure of the oil components. As would be expected, increase in temperature or hydrogen-oil ratio, or decrease in pressure, all favour increased vaporisation. It proved possible to develop a method of calculation which can be applied to many petroleum fractions.

Aid to Linguists

SO much chemical processing is done as part of the nuclear programmes that a recent four-language glossary* of terms in this field is likely to be valuable to the new generation of engineers struggling to master languages. Items are arranged in alphabetical order in English with translations and cross-indexes in French, German and Russian. In general this volume is well supplied with chemical and processing expressions but it is unfortunate that the word "fluidisation" is missing; the method is of wide interest in fuel processing and professional translators still often boggle at the word. Otherwise the normal terminology of distillation, other separations, mixing, chemical reaction and the like are well covered. Only one misprint was noted—a misspelling of the word "solvent" in entry 1588.

*"Nuclear Physics and Atomic Energy. Terms of Nuclear Physics & Nuclear Technology in English, French, German, Russian." Elsevier, London, 1960. 30s.

DIARY

University of Sheffield

June 2. In the Engineering Department. Lecture Theatre. "An Improved Approach to Certain Heat Transfer Problems. Finned tubes in Nuclear Surroundings," by Professor Burnay (University of Liège). **3.0 p.m.** (To attend please inform Professor M. W. Thring in advance).

Imperial College of Science and Technology, London

In Lecture Theatre 105, Department of Chemical Engineering. **3.15 p.m.**

May 27. "Heat transfer to liquid fluidised beds and to coarse suspensions flowing in a vertical pipe," by J. W. Smith.

June 3. "Mass transfer in liquid-liquid systems: simultaneous transfer of two solutes between two immiscible solvents," by N. G. Maroudas.

Bradford Institute of Technology

June 17-18. Special short course on "The uses of plastics and polymers in chemical engineering."

Huddersfield College of Technology

July 11-15. Summer School in Chemical Engineering. "Mass and Mass-Heat Transfer Operations."

INTERNATIONAL EVENTS

June 14, 15, 16. In Frankfurt am Main, Germany. Dechema Annual Meeting 1960. (26th meeting of the European Federation of Chemical Engineering.) "Problems of materials of construction in chemical engineering." Details from Frankfurt (Main) 7, Postfach.

June 21-30. In Belgrade, Yugoslavia. The 3rd International Exhibition of Applied Chemistry. Details from Bulevar Voivode Misica 14, Boîte Postale 408, Belgrade.

RESEARCH AS A CAREER

RESEARCH can be said to be the lifeblood of any industrial organisation. Where the chemical industry is concerned this is even more so because of the highly developed chemical industry which has long flourished on the Continent and which, with the advent of the Common Market, promises even more fierce competition to Britain's chemical industry. In view of this it is pertinent to try to discover the manner in which the chemical industry is meeting the challenge, and also to try to give some identity to the role the chemical research worker has to play in assuring the continued sale of British chemical products overseas.

To show that the chemical industry itself is alive to the vital role that research must play in ensuring its future prosperity we refer here to extracts from a recent address made by SIR OWEN WANSBOROUGH-JONES, K.B.E., C.B., a director of Albright & Wilson Ltd., a company which has just completed expansions and additions to its research facilities at a cost of £½ million.

In his address SIR OWEN said: "It is a common plaint that industry in this country has not been spending enough of its own money on research. Doubtless this is true in some areas, but I am not sure that it is a charge that can be held against the chemical industry as a whole, nor against my firm in particular. In the recent report of the Economics Committee of D.S.I.R. (of which my own chairman is a member) it is shown that, in gross, expenditure on research and development in industry has grown markedly over the recent years and the 5.9% of the value of the net output spent by the chemical and allied trades is, relatively speaking, high. Aircraft of course and electronics, both of which are also, and rightly beneficiaries of a good deal of Government support, certainly come out much higher than the national average for all industry, but the 5.9% spent by the chemical industry, a total of £43 million for the year 1958, is, despite the loading mentioned above, still markedly above the national average taken over industry as a whole."

"It is important to realise, as we do, that one must lay adequate and proportional stress on the main tasks towards which industrial research has to contribute. I think they are these: the spectacular and exciting one of the search for totally new products or processes, the painstaking but invaluable work required for the improvement of existing processes whereby the cost to the consumer can be continuously held down or reduced, and that form of technical endeavour which continually tries to ensure that the customer or the consumer really does get the best value by making the best use in the best way of the most appropriate product available."

Referring to the opportunities for advancement in his own company for the research worker, SIR OWEN said: "It is perhaps noteworthy, though I am not quite sure what it proves, that two former heads of the Research Department are now respectively chairman and deputy chairman. I think this at least indicates that my company is liable to take research and development pretty seriously, and to continue to foster it in all ways that it can."

We, too, feel that there are limitless opportunities for the young men and women who decide to make research in the chemical industry a career whether it be in the development of new processes, products or revitalising existing ones.

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Distillation Symposium

"IT is of considerable economic importance to be able to predict the separating efficiencies of plate-type and packed distillation columns under different circumstances. Ignorance in this respect leads to over-design." These opening words of the opening paper at the recent Distillation Symposium in Brighton epitomise the contribution made by its organisers.

The gaps in our knowledge of distillation are all the more surprising when we consider that the chemical industry has such an excellent record of attention to research. In the recently-published D.S.I.R. survey* the industry (which in this classification includes mineral oil refining) is picked out as the third largest investor in research and development —spending no less than £43 million in 1958. Moreover, in one aspect the industry was unique, for its two leaders in these stakes—the electrical engineering and aircraft industries—were noted as having received some 80% of the defence research contracts. The chemical industry's expenditure, however, arose largely from its own resources.

Yet despite this healthy background, the centuries-old history of distillation and the extensive attention that has been paid to it in recent years, both plant and chemical manufacturers have clearly indicated that they regard further promotion of this subject as a major interest. Although it has been one of the most publicised subjects in the field of chemical engineering, it is also the one where information is most sought. The two trade associations therefore set up an expert panel to review published information, special knowledge held by firms and gaps in existing knowledge. The panel's report† emphasised that distillation is such a fundamental operation and so much capital is invested in the equipment that even minor economies are well worth the effort. They therefore pressed for attention particularly to methods of predicting the necessary physical data and to study of the mechanism of mass transfer in distillation systems. In the field of contacting devices the chief need was thought to be extending the scope of correlated knowledge to include industrial-scale packed distillation columns. Discussing measurement and control, the panel had recommended that the mass transfer work should include studies of transient disturbances. This would enable overall mechanical design of columns to be assessed in terms of controllability; it would provide a basis of comparison of the response of liquid/vapour contacting devices and would help in selecting the most effective automatic control loops. The Institution of Chemical Engineers was invited to organise a symposium and the trade associations to support fundamental work at the universities.

What has been the reaction?

At the universities six projects covering the research subjects recomended in general terms have been duly launched. Presumably, the work at Warren Spring Laboratory, mentioned in our last issue, may have come as a bonus, for that programme too has arisen in response to the same *cri de cœur* and is intended to provide basic data. And the symposium? This has involved what is almost a highly successful, and perfectly ethical, sleight-of-hand. For, at the invitation of the Institution, the membership of the panel was virtually metamorphosed into that of an organising committee—thus, among other aspects, ensuring freedom from criticism of the latter by the former. A more important feature, however, is that this arrangement ensured that the professional chemical engineers who advised the trade associations have been fully in a position to give effect to their intentions with continuity of thought and effort. The event was well supported by a wide range of firms and organisations. With some rearrangement the basic subject pattern originally proposed was maintained. The earlier part of the proceedings dealt with fundamentals and the later parts with performance of equipment. Fundamentals were then treated under the two main heads of heat and mass transfer and of vapour-liquid equilibria. We were particularly impressed with the technique for measuring gas-liquid interfacial areas and foam densities now being developed by Calderbank and his colleagues. The method, based on measuring optical reflectivity of transparent dispersions, can be attached to a distillation column to "view" the froth through a flat glass window in the wall. The gamma-ray transmission technique can also be applied by fittings outside a column and the resultant measurements can provide data on interfacial area, gas hold-up and bubble-size.

Direct studies of effects of disturbances seemed to be lacking apart from Prof. Rademaker's work with a new mobile process-dynamics analyser measuring characteristics by means of the test disturbances method. With this equipment measurements have been made on a turbogrid column over 100 ft high to provide data for checking a general theory of column dynamics. On the other hand, there was a good deal of practical guidance on performance of columns including assessments of the commercially available directional jet-trays which use the momentum of the vapour to move the liquid across the tray. In two installations it was reported that jet-trays had given improvements in capacity of about 30% over bubble-trays at comparable efficiency and at half the cost.

This information is certainly filling a gap in our knowledge, and its contributors are drawn from many countries. Yet the final criterion of success will not be the number or range of papers presented, the vigour of the discussion nor the numbers attending. The test which will be most applied will be an eminently practical one; will engineers, following this symposium, be better able to tackle the separation of mixtures where experimental data are meagre, and will they be able to design fractionating equipment more economic ally? For the former, it is likely that they may yet have to await the results of the university projects, but there can be no doubt of the major contribution made by this event to improvements in column selection, operation and design.

* Industrial Research and Expenditure, 1958. H.M.S.O., 1960. 1s. 3d.
† Report of the Distillation Panel Recommending Some Basic Researches. May 1958. Association of British Chemical Manufacturers, British Chemical Plant Manufacturers Association.

66.982 : 531.788

NOMOGRAPHIC DESIGN OF VACUUM INSTALLATIONS*

Rapid methods for determining the dimensions of vacuum equipment are presented for molecular, viscous and intermediate flow conditions

by THEA ROTH and ING. A. ROTH

THE problems of vacuum technology in industry in general and particularly in chemical technology are becoming increasingly more numerous and complex. The trend towards higher vacua and greater displacement requires that vacuum installations be designed to function efficiently without being excessively large. To help in the design of vacuum installations we present here formulæ from the literature and graphical methods developed by us for determining rapidly the type of flow régime and the dimensions of the vacuum plant for a given duty.

I. Determination of the Type of Flow Régime

The characteristic of a vacuum pipe in relation to the flow of gases through it during evacuation is its resistance, or inversely, the conductance. The conductance is in general defined by the Equation (1).

$$C = \frac{Q}{p_1 - p_2} \qquad \ldots.(1)$$

where Q = amount of gas flowing through a section of the pipe (expressed in the units pV); and
$p_1 - p_2$ = the fall in pressure along the length of pipe.

The dimensions of conductance are, therefore, vol./time. Conductance is a function of the geometrical dimensions of the section of pipe considered and of some of the physical properties of the gas which is being evacuated through it. The conductance can be dependent or independent of the pressure, according to the flow régime.

The calculation of vacuum installations is based on three general relations, as follows:

(1) The total conductance, C, of a number of elements of conductances, C_1, C_2, C_3 ... connected in series is given by Equation (2).

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \qquad \ldots.(2)$$

(2) The conductance of these same elements connected in parallel is given by

$$C = C_1 + C_2 + C_3 + \ldots \qquad \ldots.(3)$$

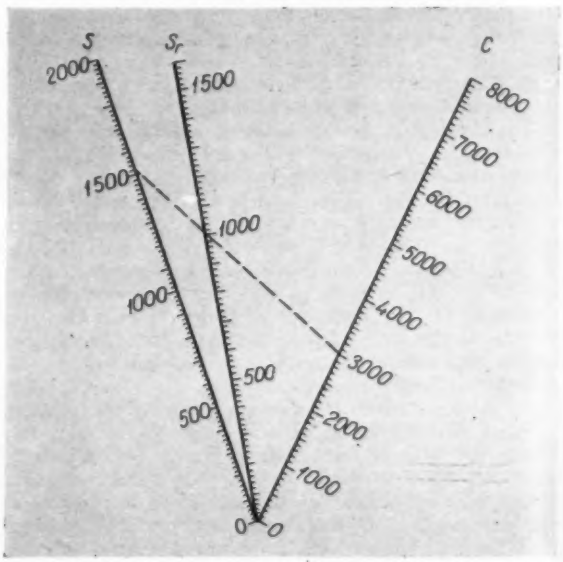
With the aid of these relations it is possible to calculate the total conductance of a complex system of pipes of various dimensions, cross-sections, valves, traps, etc., from the conductances of the individual components.

(3) A third relation connects the pumping speed with the actual speed of evacuating a receiver. The pumping speed, S, of a vacuum pump is defined as the volume of gas—measured at the pressure at which it enters the pump—which enters the pump in unit time. It can be shown[1] that a pump with pumping speed, S, can evacuate gas from a receiver to which it is connected by a pipe of total conductance, C, with an evacuating speed, S_r, given by the Equation (4).

$$\frac{1}{S_r} = \frac{1}{S} + \frac{1}{C} \qquad \ldots.(4)$$

This can be solved by nomogram (Fig. 1) which can be used with any units (cc/sec.; cc/min.; litres/sec.; cu. m/hr, etc.) provided the units used are the same for all three quantities.

Fig. 1. Nomogram for determining one of the magnitudes S, S_r or C from two of the others.



* Based on an original paper published in *Revista de Chimie* (Redactia, Str. Ion Ghica 3, Bucharest, Rumania), 1958, **II**, 618-626.

From Equation (4) it can be seen that the real speed of evacuation, S_r, approaches the pumping speed more rapidly the larger the conductance of the connection between pump and receiver. In vacuum systems, therefore, one should choose a pipe of dimensions which give the highest conductance and, therefore, leads to values of, S_r, as close as possible to the value, S, of the pump.

When making approximations in vacuum calculations it should be noted that the higher the ratio of conductance to the pumping speed, S, the smaller is the effect of an error in the calculation of the pipe on the conductance of the real evacuation speed, S_r.

Denoting $C/S = n$ (5) we obtain from Equation (4)

$$S_r = \frac{C}{n+1}$$

For the case, $C = S$, i.e. $n = 1$, the error in, S_r, will be half that in C; if $C = 3S$, the error in Sr, will be only $\frac{1}{4}$ of that of C. From Equations (4) and (5), the ratio $S_r/S = N$, the "pumping yield", is given by

$$N = \frac{n}{n+1}$$

The effect of the ratio, n, on the pumping yield, N, is clearly shown in Fig. 2.

A method will now be described for calculating the conductance of the various components of a vacuum installation (pipes, bends, traps, etc.) as a function of the flow system, the physical properties of the gases being evacuated and the dimensions of the components. In vacuum installations there can exist two types of flow:

(1) viscous flow, which occurs when the length of the mean free path of the molecules is much smaller than the diameter of the pipe; and

(2) molecular flow, when the length of the mean free path of the molecules is larger than the diameter of the pipe.

Since the transition from one type to the other occurs gradually with change of pressure there is a considerable range of pressures for which the flow may be considered as being of an intermediate type.

The conductance in the case of viscous flow is given by the Poiseuille[2] equation

$$C_v = 281\sqrt{\frac{T}{M}}\,\frac{d^4}{l\lambda} \qquad \ldots.(6)$$

where: C_v = conductance in viscous flow system, cc/sec.;
T = absolute temperature of gas;
M = molecular weight of gas;
λ = length of mean free path, cm.;
l = length of pipe, cm.; and
d = diameter of pipe, cm.

According to KNUDSEN[3] the conductance for molecular flow is given

$$C_M = 3810\sqrt{\frac{T}{M}}\,\frac{d^3}{l} \qquad \ldots.(7)$$

For intermediate flow the conductance may be expressed semi-empirically by

$$C_I = b\,.\,C_M + C_v = C_M\left(b + \frac{C_v}{C_M}\right)$$

$$= 3810\sqrt{\frac{T}{M}}\,\frac{d^3}{l}\,(b + 7.4\,10^{-3}\,d/\lambda) \quad \ldots.(8)$$

where $b = \dfrac{1 + 1.254\ d/\lambda}{1 + 1.548\ d/\lambda}$ has values between, $b = 1$, for $d/\lambda = 0$ and, $b = 0.81$, for $d/\lambda > 200$ (Fig. 3).

In order to establish the limits between molecular and intermediate flow and viscous and intermediate flow, respectively, one writes[4]

$C_I = 1.05\ C_M$
and $C_I = 1.05\ C_v$. This involves an error of 5%.

From the first relation, for $b = 1$, we have

$1 + 7.4\,.10^{-3}\,d/\lambda = 1.05$ from which $\lambda/d \approx 1.5$ .... (9)

while the second relation for $b = 0.81$ gives

$$\lambda/d = 4.6\,.\,10^{-3} \qquad \ldots.(10)$$

With an error of 5%, the molecular flow system is, therefore, satisfactorily characterised by $\lambda/d > 1.5$, and viscous flow by $\lambda/d < 4.6\,.\,10^{-3}$ while the region $4.6\,.\,10^{-3} < \lambda/d < 1.5$ corresponds to intermediate flow.

Fig. 4 allows the flow régime to be estimated rapidly and three examples are worked out for absolute pressures of 10^{-1}, 10^{-3} and 1 mm. Hg respectively.

Fig. 2. Exhaust efficiency N *as a function of ratio* n.

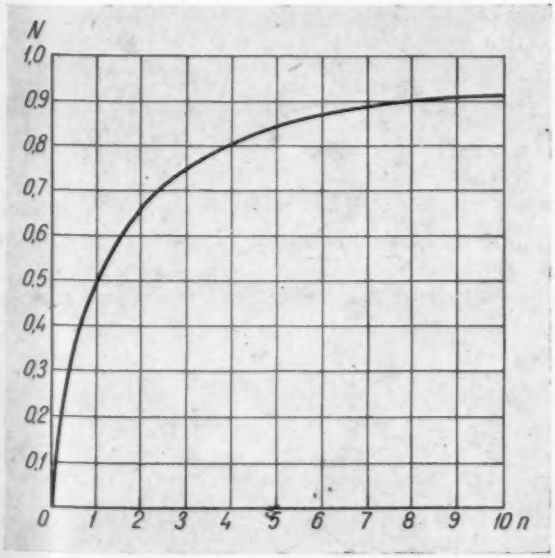
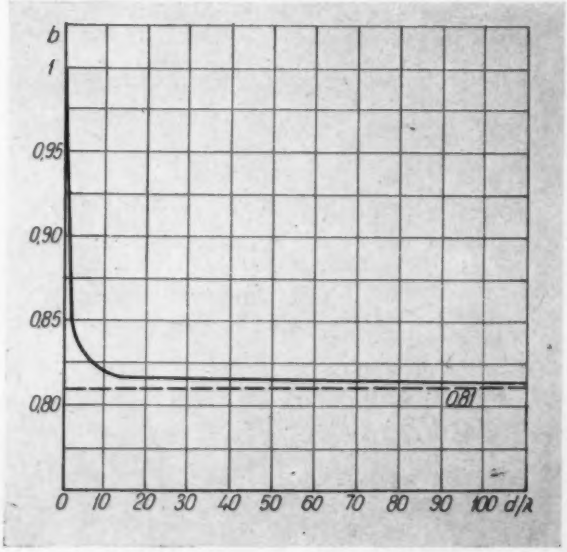


Fig. 3. Values of b *as a function of* d/λ.



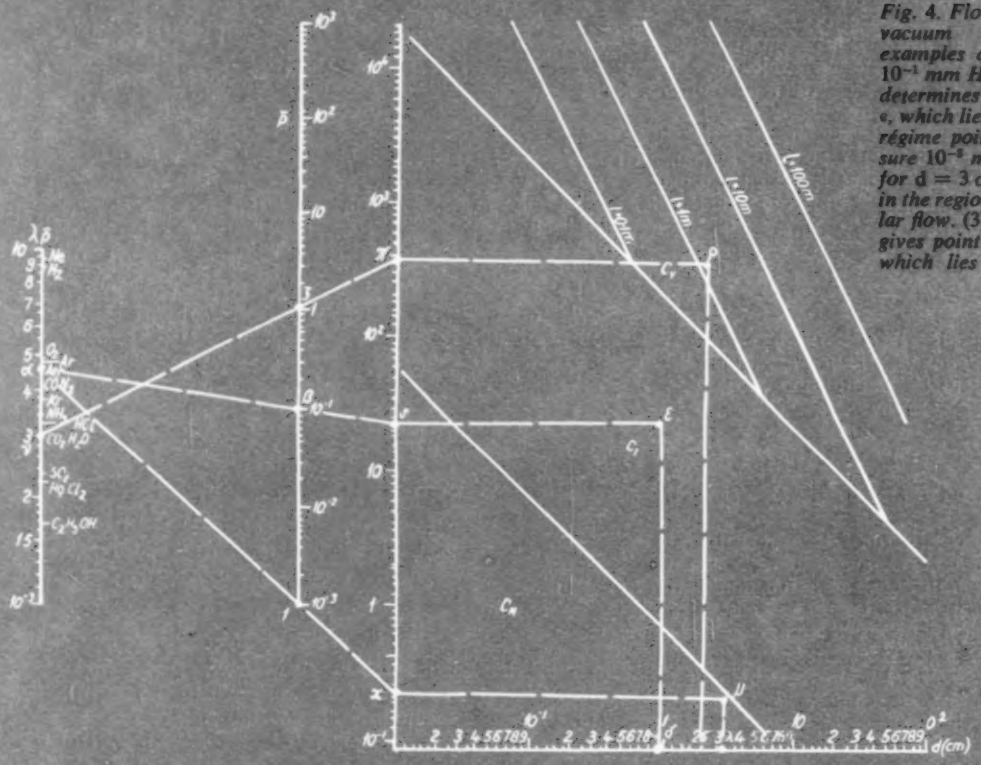


Fig. 4. Flow system nomogram for vacuum installations. Three examples are given. (1) Air (α) at 10^{-1} mm Hg (β) gives point γ which determines for d = 0.95 cm (δ) point ε, which lies in the intermediate flow régime point C_t. (2) Air, ε, at pressure 10^{-3} mm Hg (ι) gives χ: which for d = 3 cm (λ) gives μ, which lies in the region marked C_M for molecular flow. (3) CO_2 (ν) at 1 mm Hg (ξ) gives point π, d = 2 cm (σ) gives ρ, which lies in viscous flow region (C_v).

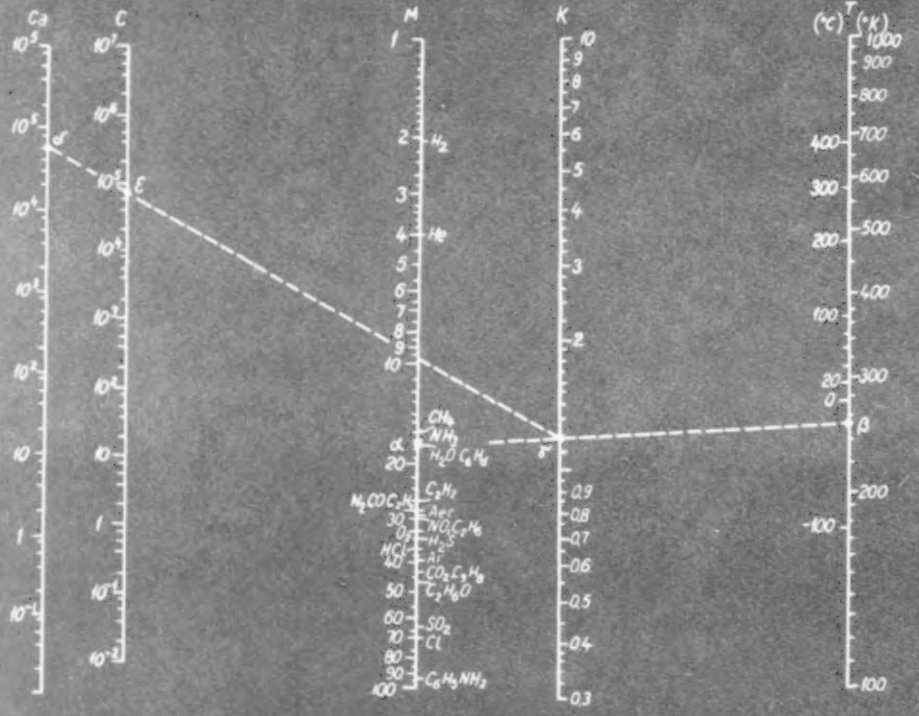


Fig. 5. Nomogram for molecular weight and absolute pressure correction. Example: water vapour (α) at temperature −20°C (β) gives K = 1.2 (γ). If the air conductance from (11) or from Fig. 6 is C_a (δ), then the conductance for this case may be obtained as the intersection of the straight line δ — γ with the scale C (ε).

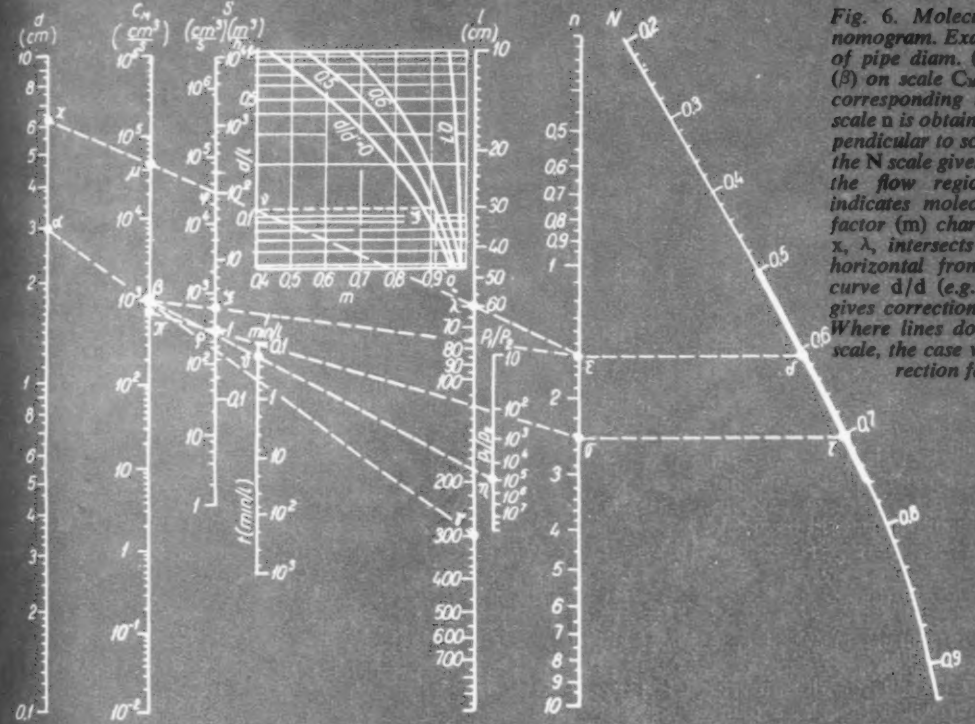


Fig. 6. Molecular flow conductance nomogram. Example: air at 20°C. Join of pipe diam. (α) and length (γ) gives (β) on scale C_M. From β and point ξ, corresponding to S, intersection ε on scale n is obtained. The line drawn perpendicular to scale n from this point to the N scale gives the pumping yield and the flow region (heavy black line indicates molecular flow). Correction factor (m) chart. The line d-l, joining x, λ, intersects scale d/l at (υ). The horizontal from this point intersects curve d/d (e.g. = 0.5) to give ξ; this gives correction factor on abscissa m. Where lines do not pass through d/l scale, the case with long pipes, no correction factor is required.

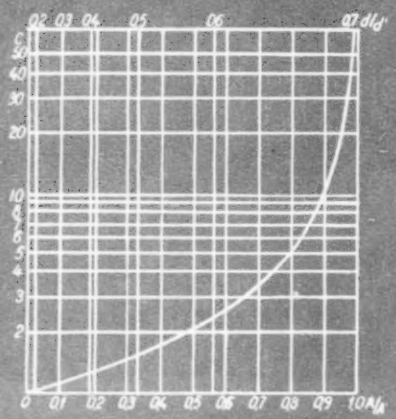


Fig. 7. The value of c as a function of A/A′ or d/d′.

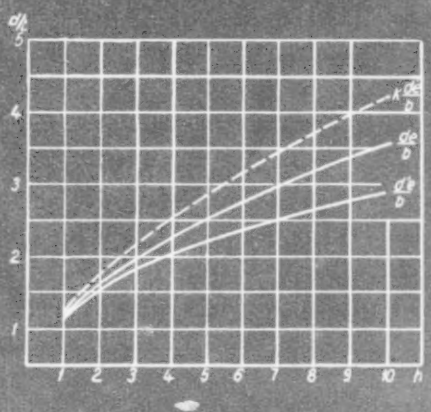


Fig. 9. Values of d_e/b as a function of h.

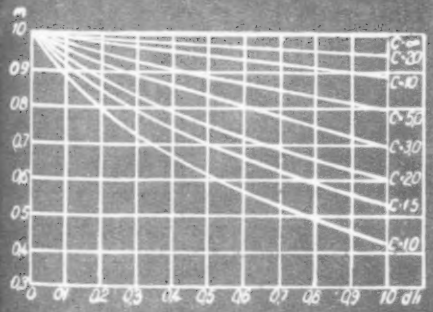


Fig. 8. Value of factor m as a function of d/l for various values of c.

The upper limits of the viscous flow régime are also given; application of Equation (6) beyond these limits leads to errors in excess of 25%.[4] For instance, point ρ being situated below the line, $l = 10$ m, corresponds to a case ($p = 1$ mm. Hg; $d = 2$ cm) which may be determined with the aid of Equation (6) as long as the length of the pipe does not exceed 10 m. If the length of the pipe is greater than 10 m. the accuracy of the calculation will not be greater than 75%.

II. Conductance for a Molecular Flow System

Pipe of Circular Cross-section, Long

A simplified form of Equation (7) for air at 20°C is:

$$C_{Ma} = 1.21 \cdot 10^4 \frac{d^3}{l} \qquad \ldots.(11)$$

where: C_{Ma} = conductance, cc./sec.; and
d and l = diameter and length of pipe, respectively, in cm.

This formula applies to an air pump (20°C) for the cases represented by the region C_M in Fig. 4. For any other gas of molecular weight, M, or at any other absolute temperature, T, the conductance will be given by:

$C_M = K \cdot C_{Ma}$, where K is given by

$$K = 0.314 \sqrt{\frac{T}{M}} \qquad \ldots.(12)$$

Fig. 5 represents a nomogram which enables one to apply these corrections rapidly.

Formula (11) may be applied, with an error less than 6%, to long pipes for which $l > 20d$, and in which case the resistance of the entrance orifice may be neglected in comparison with that of the rest of the pipe. It is applicable only for pipes of circular cross-section. The conductance of pipes of any other cross-section is smaller than that of pipes of circular cross-section having the same cross-sectional area. A rapid determination of the conductance can be made with the aid of Fig. 6.

Orifice

The conductance of an orifice of area A is given by Equation (13)

$$C_o = 3638 \sqrt{\frac{T}{M}} A \qquad \ldots.(13)$$

For air at 20°C this reduces to

$$C_{Oa} = 11550A \qquad \ldots.(14)$$

where C_{Oa} is expressed in cc/sec., and A in sq. cm. For other gases, and at different temperatures Equation (14) must be corrected with the aid of K from Equation (12), or nomogram of Fig. 5. The formula (14) assumes that the orifice of cross-sectional area, A, is small compared with cross-section, A', of the space surrounding the orifice. If this is not so then the conductance must be corrected by a factor, c, given by

$$c = \frac{A'}{A'-A} = 1/1 - \frac{A}{A'} \qquad \ldots.(15)$$

which is readily solved by the nomogram of Fig. 7.

In cases where $A > 0.1\ A'$ the error becomes inadmissible if this correction is not taken into account, since $c > 1.11$. For such cases Equation (14) becomes

$$C_{Oa} = 11550\, cA \qquad \ldots.(16)$$

In the derivation of Equations (14) and (16) no conditions have been made with regard to the shape of the orifice; the formula is, therefore, in general, applicable to any shape of orifice. It does not, however, give correct results for slit-type openings where the ratio of the longitudinal dimension to the mean free path may be much greater than the ratio of the transversal dimension to the

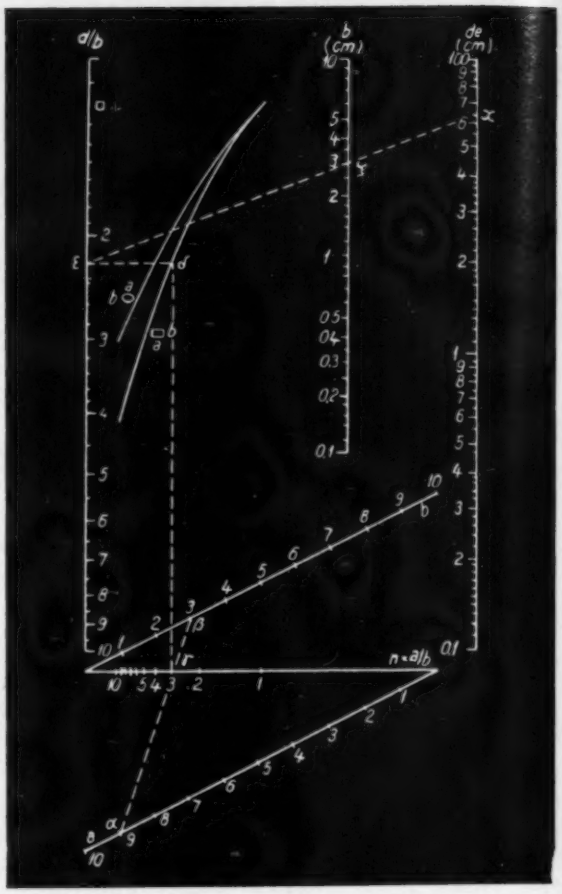


Fig. 10. Nomogram for equivalent diameter. The rectangle sides a (α) *and* b (β) *gives* h (γ). *This gives first* (δ) *and then* (e), *which, with the shorter side* b (ξ), *gives the intersection of scale* d *at* x.

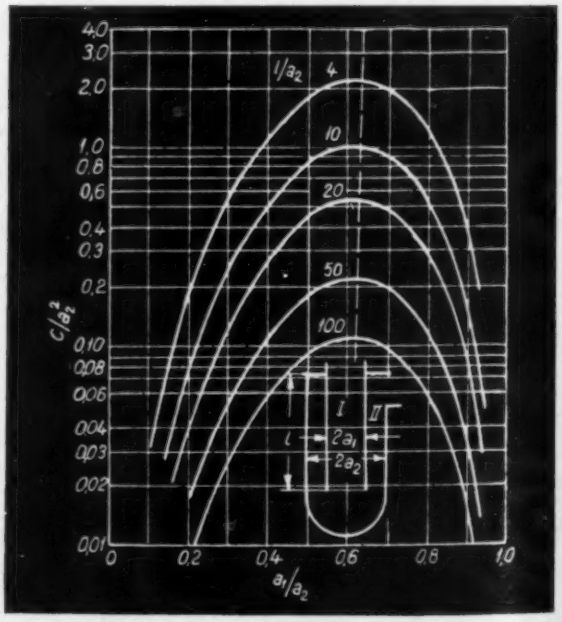


Fig. 11. Diagram for the conductance of traps.

mean free path of the molecules, the flow in the two directions following different laws, e.g., molecular and intermediate.

Short Pipes of Circular Cross section

For pipes that are short ($l < 20d$) the effects of the pipe orifice may no longer be neglected, and the conductance of such pipes is smaller than the value given by Equation (11). The conductance of such a pipe may be written as the conductance which results from connecting in series an orifice of the size of the pipe entry with the pipe itself. Combining the conductances given by (14) and (11) with Equation (2) we obtain:

$$\frac{1}{C_t} = \frac{1}{C_o} + \frac{1}{C_M} \text{ or } C_t = C_M \,.\, 1/\left(1 + \frac{C_M}{C_o}\right)$$

for an orifice of circular cross-section, $A = \frac{\pi d^2}{4}$, and C_t is given by

$$C_t = 3810 \sqrt{\frac{T}{M}} \left(\frac{d^3}{l + 1.33\, d}\right) \qquad \ldots.(17)$$

which for air at 20°C reduces to

$$C_{ta} = 1.21\ 10^4 \frac{d^3}{l} \cdot \left(\frac{1}{l + 1.33\, d/l}\right) \qquad \ldots.(18)$$

For $l = 0$, Equations (17) and (18) reduce to that for an orifice, while for $l > 20d$ it assumes the form of that for the conductance of a long pipe. For $l = 20d$, the application of Equation (7) in place of (17) will result in an error of 6%.

Putting $$\frac{1}{l + 1.33\, d/l} = m_1$$

we obtain

$$C_t = 1.21\ 10^4\, m_1 \frac{d^3}{l} \qquad \ldots.(19)$$

The value of m_1 can be read off directly from the diagram of Fig. 8, curve $c = 1$. If the orifice of the pipe is large compared with its surroundings, then the formulæ for short pipes need to be corrected by a factor, c, (Equation 15, Fig. 7) which gives Equation (20). The value of, m, can be read off from the diagram of Fig. 8.

$$C_t = 1.21\ 10^4 \frac{d^3}{l} \cdot \frac{c}{c + 1.33\, d/l} \qquad \ldots.(20)$$

$$= 1.21\ 10^4\, m \frac{d^3}{l}$$

For example for a pipe $l = 10$ cm., $d = 10$ cm. and the diameter of the surrounding area $d' = 15$ cm., the conductance given by Equation (19) is only 0.435 of the value given by Equation (11) and that given by Equation (20) is 0.644 times the same value (11). To make corrections of this type a small diagram for corrections, $m - d/l$, has been included in Fig. 6.

Pipes of Rectangular Cross-section

For a pipe of any cross-section it is possible to find the equivalent pipe of circular cross-section from the point of view of conductance per unit length. After determination of the diameter of the equivalent pipe, the problems of conductance of rectangular pipes may be treated with the aid of the formulæ and nomograms which have been deduced for circular cross-sections.

Two methods are used for the determination of the equivalent diameter of a pipe of rectangular cross-section. In the first one it is assumed that the two pipes are equivalent if their cross-sections are of equal area. On this hypothesis the equivalent diameter of a pipe of rectangular cross-section with sides, a, and, b, is

$$d_e = 2\sqrt{\frac{a \,.\, b}{\pi}} \qquad \ldots.(21)$$

$$\frac{d_e}{b} = 1.13\sqrt{h} \qquad \ldots.(21')$$

setting $a/b = h$ we obtain Fig. 9.

The other method is based on an expression of the conductance of a pipe of length, l, and variable cross-section, A_l, and perimeter, P_l, in the form of Equation (22)

$$C = \frac{19400 \sqrt{\frac{T}{M}}}{\int_0^l \frac{P_l}{A_l^2}\, dl} \qquad \ldots.(22)$$

Solution of the integral of Equation (22), and equating with formula (7) gives the equivalent diameter as Equation (23)

$$d'_e = 1.72 \sqrt[3]{\frac{A^2}{P}}$$

$$= 1.37 \sqrt[3]{\frac{a^2 b^2}{a+b}} \qquad \ldots.(23)$$

and $a/b = h$, gives

$$\frac{d'_e}{b} = 1.37 \sqrt[3]{\frac{h^2}{h+1}} \qquad \ldots.(23')$$

A comparison of the results obtained with the aid of formulæ (21) and (23) with values established by experiment has shown that both formulæ give results which are tolerably in agreement only when the cross-section does not deviate too much from a square. $(h < 3)$[6]. Formula (21) gives better results than Formula (23) (see Fig. 9). Both formulæ lead to errors which increase with the length to breadth ratio of the rectangle (i.e. with increase in h). These formulæ may be applied as follows:

Formula (21) in the interval $1 \leq h \leq 4$ (curve d_e/b— Fig. 9); Formula (23′) corrected by a factor k for $h > 3$ (curve $k \,.\, d'_e/b$ — Fig. 9). In the case of a square cross-section, Formula (23′) becomes:

$$d'_e = 1.08\, b$$

but to agree with experiments one uses formula (24) $= d'_e = 1.2b$ .... (24′) where b is the side of the square.

For a square cross-section and for air at 20°C we have, therefore:

$$C_M = 2.08\ 10^4 b^3/l \qquad \ldots.(25)$$

For other gases and at other temperatures one must correct the result by a multiplying factor K (Fig. 5). The equivalent diameter may be estimated rapidly with the aid of the nomogram of Fig. 10.

For the case of an elliptic cross-section with axis, a, and, b, Formula (22)—with $A = \frac{\pi}{4}\, a.b$ and $P = \pi\sqrt{(a^2+b^2)/2}$ —gives for air at 20°C

$$C_M = 3.45\ 10^4 \frac{a^2 b^2}{l\sqrt{a^2+b^2}} \qquad \ldots.(26)$$

by setting $a/b = h$ we obtain

$$\frac{d_e}{b} = 1.41 \sqrt[3]{\frac{h^2}{(h^2+1)^{\frac{1}{2}}}} \qquad \ldots.(26')$$

The equivalent diameter can be determined in this case with the aid of the nomogram of Fig. 10 in the same way as for a rectangular cross-section earlier on.

Tapered Pipes (Circular Section)

Substituting in Formula (22) $P_1 = \pi(d_o + \alpha l)$ and $A_1 = \frac{\pi}{4}\,(d_o + \alpha_l)^2$, where, α, is the taper angle and, d_o, the diameter of the narrower end, by integration one obtains

$$C_M = 1.21\ 10^4 \frac{d_o^2\, d_l^2}{d_l \,.\, l} \qquad \ldots.(27)$$

in which d_o, $d_{\frac{1}{2}}$, and d_1 are the diameters of the smaller end, the middle and the larger end (in cm.) of a pipe of length, l, cm.

Truncated Pyramidal Pipes of Square Cross-section.

With side b. The conductance of such a pipe may be calculated with the aid of a combination of Formulæ (27) and (24), i.e. with the aid of Equation (28)

$$C_M = 2.08\ 10^4 \frac{b_o^2\ b_l^2}{b_{\frac{1}{2}} \cdot l} \qquad \ldots.(28)$$

From Equations (27) and (28) it follows that if $d_1 < 2d_o$ and $b_1 < 2b_o$ for pipes which taper it is possible to treat these with the aid of formulæ which are applicable to pipes of constant cross-section, i.e., Equations (11) and (25) respectively, by substituting the mean diameter of the portion considered. ($d = d_{\frac{1}{2}}$; $b = b_{\frac{1}{2}}$). For short pipes ($l < 20d$) it is again necessary to apply the end corrections of Formula (18).

Pipes of Indeterminate Length or Irregular Cross-section

In some cases one has pipes which are cut at an angle at both ends or just at one end in which case the length becomes indeterminate; in others there are sections of variable cross-section the form of which is not as easily expressed as in the case of Equations (27) and (28). In such cases it is not possible to calculate the exact value of the conductance. By making certain assumptions as to the limits it is possible to calculate minimum and maximum values of the conductance between which the true value is to be found. In any estimation of conductance it is preferable to underestimate rather than to over-estimate.

Conductance of Traps

The conductance of these pieces can only be calculated exactly for the cases in which there is a simple geometrical shape. In more complicated cases one makes use of the rules outlined for pipes of irregular cross-section. The conductance of traps has been established (for air at 20°C)[3] by means

$$C_e = 3.62\ 10^4\ a_3^3\ f(X, Y) \qquad \ldots.(29)$$

where $$f(X, Y) = \frac{X^3(1+X)(1-X^2)}{X(1-X)+\frac{3}{8}\ Y\left[X^3+(1-X)(1-X^2)\right]}$$

$X = a_1/a_3$, while $Y = 1/a_2$, the dimensions a_1, a_2 and 1 being those of Fig. 11.

Bends and Angles

There is little literature on this subject which might indicate the effect of the various bends and angles in vacuum piping on the conductance as a function of shape and dimensions. All calculations for curves and bends are based on empirical methods and involve as a rule an increase of the axial length of the pipe by 3-5 times the diameter of the pipe (in calculation) for each curve or bend (the factor 5 applies to right-angled bends).

It is seen that the effect of such pieces in the case of appreciable length of piping (Equation (11)) is quite small and may be neglected in calculations as long as these are not too numerous in comparison with the overall length of the pipe. Their presence cannot, however, be neglected when the ratio of diameter to length of the pipe requires the application of Formula (18).

III. Conductances for Viscous Flow

Long Pipe of Circular Cross-section

A simplified form of Formula (6) for air at 20°C is

$$C_{vs} = 1.88\ 10^5 \frac{d^4}{l}\ \bar{p} \qquad \ldots.(30)$$

in which, C_{vs}, is the conductance in cu. cm./sec.; d and l, are diameter and length of the pipe and, $\bar{p}$, is the mean of the pressures at both ends of the pipe in mm. Hg.

$$\bar{p} = \frac{p_1 + p_2}{2}$$

In contrast with the similar case of molecular flow (Formula 11) the conductance in a viscous régime of flow also depends on the average pressure. Any value of the conductance in a viscous flow régime must therefore be related to the pressure, p.[8] For this reason the first problem in all calculations concerning viscous flow is to determine a suitable pressure on which to base one's calculations; this pressure must be chosen in such a way as to give suitable conductance not only at this pressure but also at any other pressure that may develop in the pipe.

From calculations it becomes evident that this pressure is the minimum pressure realised in the pipe under given conditions. From Relation (1) we obtain

$$\frac{C_v}{\bar{p}} = \frac{2Q}{p_1^2 - p'^2_2} \qquad \ldots.(31)$$

taking into account also the relation $Q = p_1 S_r = p'_2 S$ and noting that $\frac{S_r}{S} = \frac{p'_2}{p_1} = N$ we obtain

$$\frac{C_v}{\bar{p}_1} = \frac{2N}{1-N^2}\frac{S}{p_1} = x\frac{S}{p_1} \qquad \ldots.(32)$$

This equation is solved nomographically (Fig. 12) for air at 20°C.

Short Pipe

The establishment of an end correction for a short pipe in a viscous flow régime is extremely difficult, if not impossible, because the conductance of entrance orifice depends not only on its area, but also on the shape of the orifice, as well as the density and rate of flow of the gas. It has been established experimentally that the end effect for pressures over 0.2 mm. Hg. may be allowed for in calculations by increasing the length of the pipe by 1-2 diameters.

Pipes of Cross-sections other than Circular

Very little information is available for estimating the conductance of pipes having cross-sections other than circular. It has been suggested that if pipes of square cross-section or nearly square cross-section ($b/a < 0.6$) are treated in the same way as circular pipes of the same cross-sectional area, that there is a maximum error of 10%. For rectangular cross-sections having $b/a > 0.6$, the conductance falls rapidly in such a manner that for a pipe with $b/a = 0.1$ the conductance is only $\frac{1}{4}$ of that of a circular pipe of the same cross-sectional area. From these data it is possible to deduce, on a semi-empirical basis, an equation for the equivalent diameter:

$$d_e = 1.13\sqrt{3.34\ b^3 + 0.66\ ab} \qquad \ldots.(33)$$

IV. Conductance in a System with Intermediate Type of Flow

Formula (8) may be written for air at 20°C

$$C_I = 1.21\ 10^4 \frac{d^3}{l}\beta \qquad \ldots.(34)$$

where $$\beta = \left\{\frac{1+264\ d\ .\ \bar{p}}{1+328\ d\ .\ \bar{p}}\right\} + 15\ .\ 7d\ .\ p$$

Equation (34) becomes identical with Equation (11) for very small values of $\bar{p}$ and identical with Equation (30) for large values of $\bar{p}$. Since the quotient

$$\frac{1+264\ d\ .\ \bar{p}}{1+328\ d\ .\ \bar{p}}$$

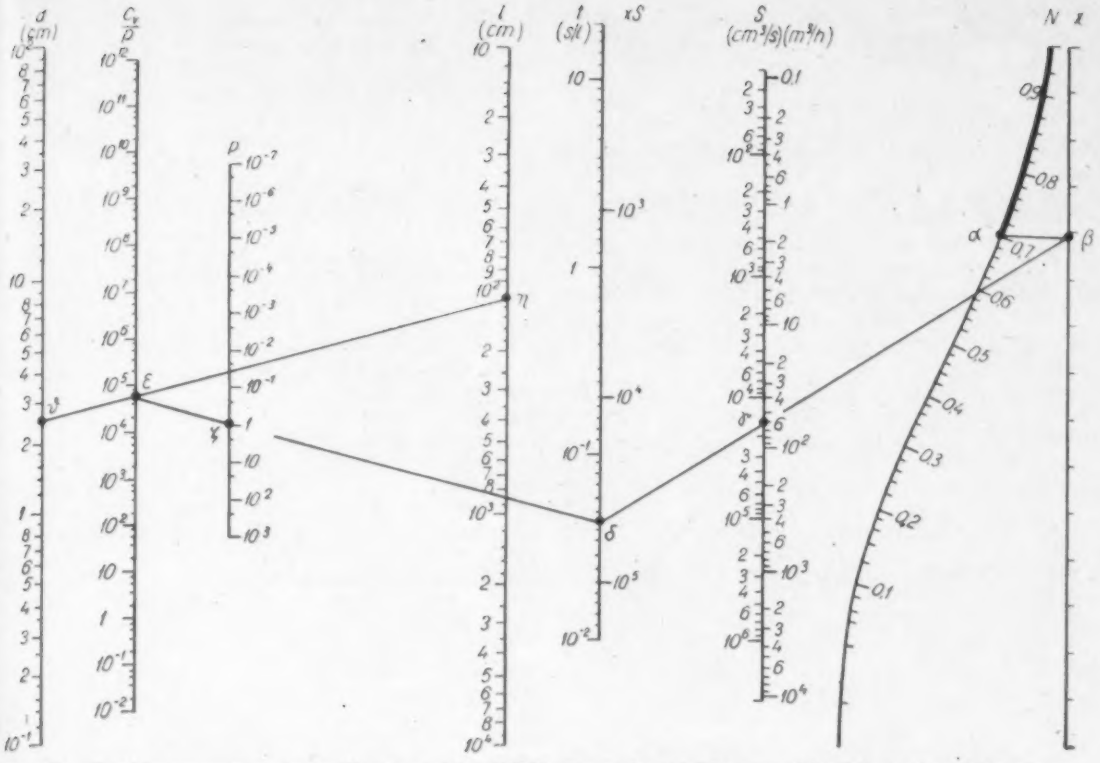


Fig. 12. Nomogram for viscous flow (e.g., air at 20°C). From the pipe diameter, (υ), and pipe length (η), we obtain C_v/p (ε). From this and the pressure (ξ) we obtain xS (δ). Pump displacement S (γ) gives the value x (β) and thus the pumping yield N (α). The pipe diameter for a given "pumping yield" to evacuate a given vessel in a given time may also be calculated by this nomogram.

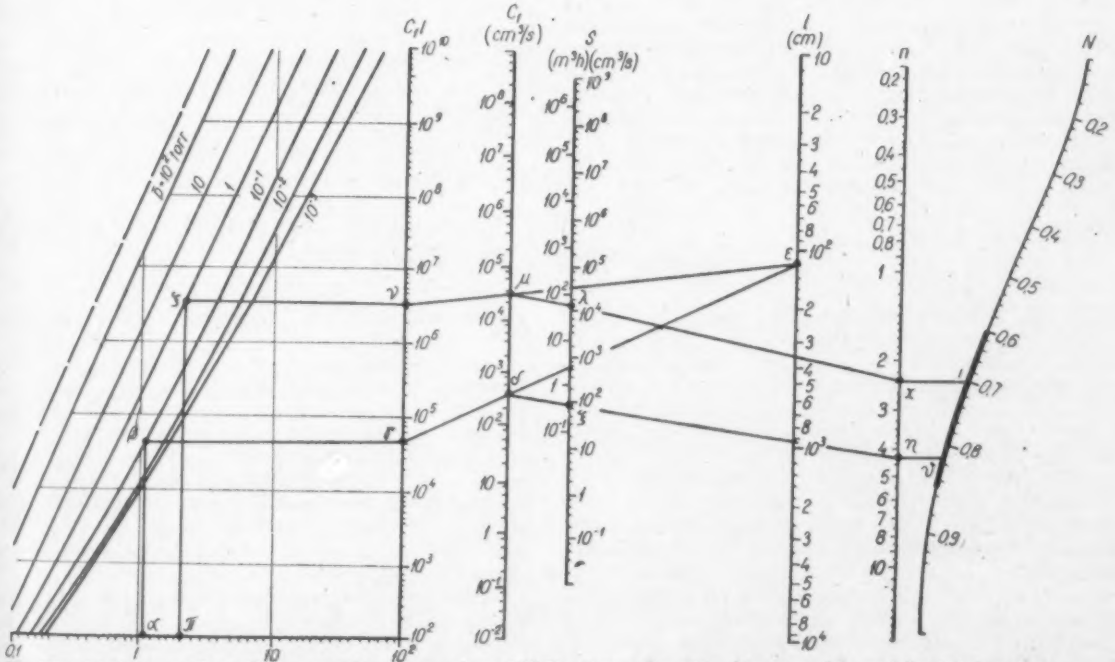


Fig. 13. Intermediate flow nomogram (e.g. air at 20°C). From the pipe diameter, (υ), and by joining the pressure point we obtain (γ). The intersection of the line γ — ε with scale C_I (δ) gives pipe conductance (of length corresponding to (ε)). Point δ and the pump displacement (point ξ) gives n, (η), and (θ) N. This gives n, which, when combined with the value of C_I, determines the displacement, S.

varies only insignificantly in the region defined as intermediate flow (Equations (9) and (10)), Equation (34) may be written in a simplified form, as

$$C_I = 1.21\ 10^4\ \frac{d^3}{l}\ (1+ 15.7\ d\ \bar{p}) \qquad \ldots.(35)$$

The nomogram of Fig. 13 allows this equation to be solved rapidly.

V. Period of Exhaust

The general formula for the duration of evacuation results from the equality of the quantity of gas which leaves the recipient and that which enters the pipe:

$$S_r\ p\ dt = -V\ dp \qquad \ldots.(36)$$

Combining this with Equations (4) and (5) we obtain

$$dt = -V\left(\frac{1}{S}+\frac{1}{C}\right)\frac{dp}{p} = -\ V\frac{n+1}{C}\frac{dp}{p} \qquad \ldots.(37)$$

Integrating this equation for the three types of flow one obtains:

—for molecular flow:

$$t_M = 2.3\ (n+1)\ \frac{V}{C_M}\log\frac{p_1}{p_2} \qquad \ldots.(38)$$

—for intermediate flow (air):

$$t_I = \frac{2.3}{0.9}\ (n+1)\ \frac{V}{C_I}\left(\log\frac{p_1}{p_2} - \log\frac{0.9+7.8\ dp_1}{0.9+7.8\ dp_2}\right) \qquad \ldots.(39)$$

—for viscous flow:

$$t_v = \frac{2V\ (n+1)}{C_V\sqrt{\bar{p}}}\left(\frac{1}{p_2}-\frac{1}{p_1}\right)$$

$$\approx \frac{2V}{(1-N)p_2C_V\sqrt{\bar{p}}} \qquad \ldots.(40)$$

The duration of evacuation, based on unit capacity (min./litre, sec./litre) may be determined directly from the nomograms of Figs. 6 and 12. On Fig. 6, the time, t (min./litre) is determined from C_M (point β) and p_1/p_2 (point η). According to Equation (38) the value read off from scale, t (point υ) must be multiplied by, $(n+1)$ read off on scale n (e.g., point ϵ). On Fig. 12, the duration, t (sec./litre) may not be read off directly and is not the actual value, i.e. does need to be multiplied with $1/1-N$. In this nomogram scale, t, has been placed on scale $\varkappa S$ in such a way that the point (e.g., δ) which indicates the value of $\varkappa S$ does not indicate at the same time the value of t.

VI. Calculation of Dimensions of Installations

In working out the dimensions of an installation one proceeds usually from the pumping yield, N, which is selected according to domain likely to obtain in installation.

In the case of low vacuum plants in which the pumping speed does not exceed a few hundred litres per sec., the flow is viscous, and the diameter of the piping is of the order of a few cm., one generally takes a value of $N > 0.85$.

In the case of vacuum installations for higher vacuum smaller values of N are used, for in these cases the pumping speed is of the order of thousands of litres per sec., and the conductance for molecular flow is smaller than for viscous flow. In a specially correct design one may reckon with $0.75 > N > 0.5$. In the case of intermediate type of flow the values of N vary usually between 0.6 and 0.85.

The region of values of N appropriate to each type of flow has been traced in thick lines on the N-scales of the nomograms of Figs. 6, 12 and 13. Starting from a selected value of N one tries to find the dimensions of the pump for a given pipe-work, a pipe-work for a given pump, or the diameter of the pipe and the speed of the pump for a given duration of evacuation. All these calculations may be carried out rapidly with the aid of the nomograms on Figs. 6, 12 and 13.

In those cases in which one is interested in determining the diameter of the pipe it is not possible to determine the type of flow with the help of the nomogram of Fig. 4. One, therefore, makes a provisional calculation of the diameter with the aid of the nomogram for intermediate type of flow (Fig. 13), and uses this value of the diameter subsequently to determine the type of flow (on Fig. 4). After the determination of the type of flow one repeats the calculation on the nomogram appropriate to the type of flow established.

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Ceramic Filters for Acid Mist

ALTHOUGH sulphuric acid mist generally forms only a small part of the total acidity of the exit gases of sulphuric acid plants, its nuisance value may be considerable. However, a new process, known as "Ceramic Filter", which is patented for acid mist removal and exploited under a licence from the German Lurgi Co. by Huntington, Heberlein & Co. Ltd., is now available in the U.K. The first unit installed in this country has now proved its value in about 15 months of operation. It deals with the exit gases of a Kachkaroff-type sulphuric acid plant at the Phoenix Wharf Chemical Works of the South Eastern Gas Board, which has a rated daily output of 50 tons of sulphuric acid calculated as 100% H_2SO_4. Formerly, sulphuric acid fumes could be seen descending slowly over a considerable distance. Since the new process has been in operation, acid fumes are no longer visible and it is only occasionally that small amounts of nitrogen oxides can be noticed.

The exit gases of the acid plant are now drawn by a fan through the "Ceramic Filter" from the base of the stack, through which they previously passed direct to atmosphere. In the filter the mist-containing gases pass through tubes made of a ceramic material of controlled porosity from the inside to the outside; the mist particles coagulate and liquid acid runs down the outside of the filter tubes. The acid thus obtained is collected from the base of the filter and returned to the Kachkaroff plant. Exit gases can be freed from acid mist at pressure losses as low as 6 in. w.g. and it has been found that the efficiency of acid mist removal is generally between 98% and 99%. The quantity of acid mist in the exit gases is mostly reduced to below 0.01 grain SO_3/cu. ft.

Owing to the presence of small quantities of solids in the exit gases, the pressure drop through the ceramic filter material increases slowly. The South Eastern Gas Board have found, however, that a set of filter tubes needs cleaning by water or steam only after a run of approximately three months and that the cleaned filter tubes can be used again.

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PHYSICAL CHEMISTRY OF VACUUM TREATMENT OF MOLTEN METALS

A discussion of factors influencing the state of a vacuum melt after a given time of treatment

by R. G. WARD,* M.A., Ph.D.

DURING the last decade the vacuum melting and casting of metals has grown from being largely of laboratory importance, involving small melts often only of a few grams of metal, to widely-used commercial processes producing ingots up to 250 tons in weight. This increasing application has been stimulated by the industrial and military demand for reactive metals such as titanium and molybdenum, which cannot be air-melted successfully. This in turn has resulted in developments in vacuum technology which have made it an economic proposition to vacuum treat less exotic metals and many iron- and nickel-based alloys are so treated.† These can also be produced under normal atmospheric conditions and the increased quality of the vacuum-treated product must outweigh the additional cost of vacuum treatment.

Vacuum treatment of molten metal can result in a higher grade product due to the reduction in the quantity of many unwanted constituents. Thus the gas content of the melt may be lowered substantially, resulting in ingots and castings of high density; the volatilisation of many undesirable impurity elements may occur to a useful extent as also can a reduction in non-metallic inclusions (oxide and silicate) which reduce the fatigue properties.

Effect of Vacuum Treatment Conditions on Equilibrium

Thermal Decomposition of Oxides

The effect of changing from atmospheric to vacuum melting on the stability of the compounds involved in melting and casting can conveniently be discussed by referring to free-energy diagrams of the Ellingham[1] type.

In the diagram shown in Fig. 1 curves are given for the variation with temperature of the standard free-energy ($\triangle G^\circ$) of formation of pure oxide from pure metal and 1 gram mole of oxygen at 1 atm pressure. Large negative free-energies indicate great stability of the oxide, and from the upward slopes of curves for the non-gaseous oxides it is apparent that their stability decreases with increasing temperature. This decreasing stability eventually results in spontaneous thermal decomposition at the temperature given by the intersection of the free-energy curve with the $\triangle G = O$ axis. The curves refer to operation under atmospheric conditions (strictly to oxygen at 1 atm pressure, but the difference is within the limits of experimental error)

TABLE I—Equilibrium Concentrations of Impurity and Alloying Elements in Iron at 1600°C and 10^{-6} Atm

Solute Element	As Pure Solute Element		In Solution in Iron	
	Vapour Pressure, atmospheres[6]	Boiling Point, °C[4]	Raoultian Activity Coefficient, γ°[7]	Equilibrium Concentration, wt.%
Mg	23	1103	—	0
Pb	$4.5.10^{-1}$	1750	>1	0
Mn	$3.5.10^{-2}$	(2150)	1	0.028
Cu	$1.1.10^{-2}$	(2500)	12	0.085
Al	$4.0.10^{-2}$	(2500)	0.043	0.276
Cr	$1.3.10^{-2}$	(2330)	1	0.702
Ni	$4.8.10^{-5}$	(3100)	1	22
Si	$9.1.10^{-4}$	(2600)	0.0174	32
Co	$2.2.10^{-5}$	(3000)	1	46
Ti	$1.2.10^{-6}$	>3000	(.05)	100
Mo	3.10^{-10}	(4700)	1	100
W	8.10^{-10}	(6000)	1	100

and it is apparent that only NiO and CoO are likely to be decomposed at moderate temperatures.

The effect of a substantial reduction in pressure is to render the non-gaseous oxides much less stable and this is shown by a reduction in their free-energies of formation from the values ($\triangle G^\circ$) given in Fig. 1 to a value predicted by the van't Hoff isotherm which, for the formation of an oxide according to the general scheme:

$$nA + O_2 = mA_xO_y$$

gives the free energy of formation as:

$$\triangle G = \triangle G^\circ + RT \ln \frac{a^m AxOy}{a^n A \cdot p_{O_2}} \quad \ldots.(1)$$

where a_A, a_{AxOy} are Raoultian activities of metal and oxide respectively. In the present case of a change in the oxygen pressure, Equation (1) gives:

$$\triangle G = \triangle G^\circ - RT \ln p_{O_2}$$

and the correction for reduced pressure in Fig. 1 is most easily made by referring the free-energies of formation, not to the base line ($\triangle G = O$) but to a line obeying:

$$\triangle G = RT \ln p_{O_2}$$

In Fig. 1 two such lines are plotted appropriate to oxygen pressures of 10^{-5} and 10^{-6} atmospheres which are typical of vacuum melting practice. The intersections of these new base lines by the free-energy of formation curves indicate thermal decomposition of oxides at much lowered temperatures under reduced pressure. At the temperatures normally used for melting metals such as iron, nickel and cobalt in induction furnaces, usually less than 1700°C, the normal refractory oxides are still stable and are used for crucible linings. However, in "consumable electrode"

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† Frequently for only a portion of the melting and casting sequence, to reduce capital expenditure on vacuum plant.

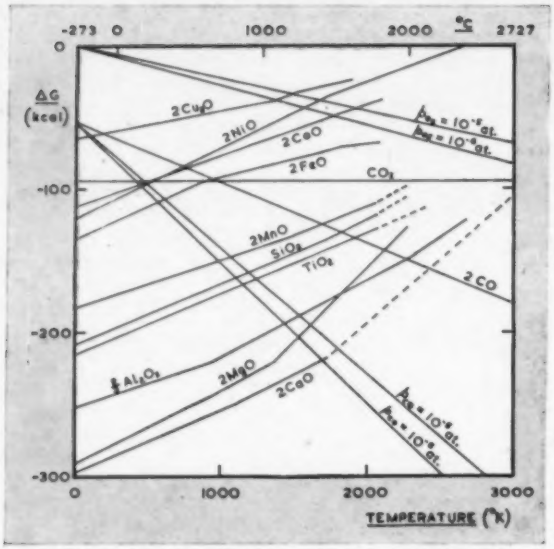

Fig. 1. Variation with temperature of the free energy of formation of oxides of interest in vacuum melting (data largely from [2]).

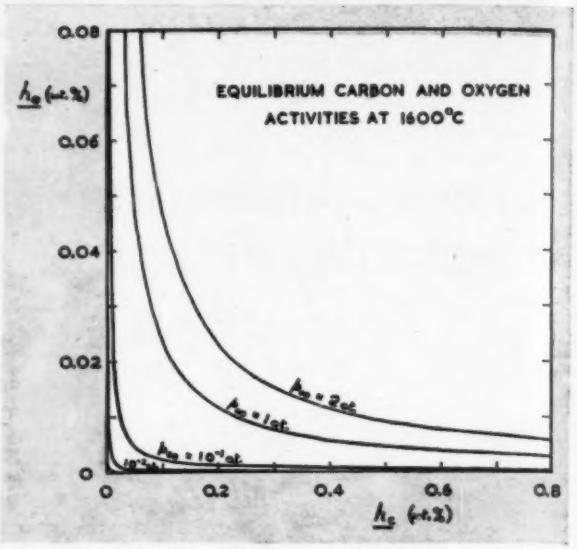

Fig. 2. Effect of carbon monoxide pressure on the Henrian activities of carbon and oxygen in equilibrium in molten iron at 1600°C.

arc melting processes in which the metal is transferred from an electrode of raw material through an electric arc into the ingot, the operative temperature exceeds the boiling point of the metal and is above 3000°C for iron, 3500°C for titanium and 5000°C for molybdenum. Under these conditions no refractory materials are stable and water-cooled copper moulds are used. It is found that the ingots produced are considerably freer from non-metallic inclusions (oxides, sulphides, silicates) than the initial electrode material, due to thermal decomposition.

Chemical Reduction of Oxides

Although Fig. 1 shows that thermal decomposition is unlikely to be a serious problem in vacuum induction melting, chemical reduction of refractory materials is a serious problem if the product is gaseous, so that the reaction is encouraged by decreased pressure. (Le Chatelier's Principle.) This is why reduction by carbon is important.

At atmospheric pressure the reduction of oxides by carbon occurs if carbon monoxide is more stable than the oxide in question, i.e., at temperatures above the intersection of the line on Fig. 1 for 2 CO by that of the oxide. The effect of vacuum conditions is predictable from Equation (1) and lowers the line for the formation of CO to:

$$\Delta G = \Delta G^\circ + RT \ln p^2_{co}$$

which lowers the temperature for the reduction of oxides by carbon. Carbon monoxide formation lines appropriate to partial pressures of 10^{-5} and 10^{-6} atmospheres are plotted in Fig. 1, and it is clear that all oxides are reduced by pure carbon above about 1500°C.

More generally, carbon is present in molten metal with an activity considerably less than unity and the possibility of the carbon reduction of refractories must be checked by correcting the line for the free-energy of formation of carbon monoxide using Equation (1). Although reduction is frequently possible, e.g., reduction of magnesia occurs if the carbon content of molten iron is above about 0.01%, the rate of the reaction is usually too slow to cause any significant fall in carbon content of the melt.

The reduction of dissolved oxide in solution in iron by dissolved carbon is of great practical interest, and the equilibrium activities of oxygen and carbon in iron at 1600°C are given in Fig. 2. The reaction may be written:

$$C + O = CO$$

for which the equilibrium constant is[3]:

$$K = \frac{p_{co}}{h_c \cdot h_o} = 450 \qquad \ldots . (2)$$

where h_c, h_o are Henrian activities. These are approximately equal to the concentrations of carbon and oxygen respectively for low-carbon low-alloy steels, although they are strictly related to concentration by:

$$h = \text{wt}\% \cdot f_1 \cdot f_2$$

where the activity coefficients f_1, f_2, etc., representing the effect of elements 1, 2, etc., on the activity, may differ substantially from unity in alloyed steels.[4]

The oxygen in equilibrium with carbon in pure iron at atmospheric pressure is sufficient to cause extensive carbon monoxide evolution during solidification, resulting in unsound low-density ingots, and the oxygen content is conventionally reduced by adding deoxidising elements, e.g., Al, Si, Mn, which form more stable oxides than iron (i.e., below the 2FeO line in Fig. 1). Although this practice satisfactorily prevents unsoundness, many of the deoxidation products are found scattered throughout the solidified steel as undesirable "non-metallic inclusions" which detract from the mechanical properties. Deoxidation by carbon, however, leaves no solid deoxidation products, and Fig. 2 and Equation (2) suggest that extremely low oxygen levels should be attainable under vacuum conditions, e.g., a millionfold decrease in oxygen content should result from a similar decrease in pressure, i.e., to 10^{-6} atmosphere.

Recent work[5] has shown only a tenfold decrease in oxygen content occurs in 12-kg steel melts due to vacuum melting. This disappointingly small drop in oxygen content is no doubt due to the fact that most of the carbon monoxide is evolved on the bottom of the crucible where the internal pressure in the bubbles is slightly greater than the ferrostatic pressure, which in this case is about one-tenth of an atmosphere. Experiments involving the artificial provision of bubble nuclei by blowing argon gas through the vacuum melt have resulted in a further tenfold reduction in oxygen content, and this is sufficient to achieve sound ingots without the use of additional deoxidisers.

Rate of Reactions

Although thermodynamic considerations will predict the equilibrium conditions, equilibrium is not always attained in a reasonable time‡ due to the slowness of some of the steps in the process; e.g., in the case of deoxidation of iron by carbon, the diffusion of oxygen to the reaction site can be rate limiting.

Practically all reactions in vacuum melting are found to follow first-order kinetics, i.e., the rate is proportional to the concentration of one of the reactants:

$$\text{i.e., Rate} = \text{const.}\,[\text{concentration}] \qquad \ldots . (3)$$

This is shown by all gas evolution processes and is explicable if the rate-limiting step is the diffusion of gas through a semi-stagnant metal film or boundary layer of perhaps 0.001 in. thickness at the metal-gas interface. Fig. 3 represents the gradient of a diffusing element in the neighbourhood of the interface, and it will be seen that the major portion of the activity drop between the bulk of the metal and the gas occurs across the boundary layer on the metal side of the interface. Turbulent stirring prevents gradients being established in the bulk of the metal and gas a short distance away from the interface. In this figure Henrian activities are used rather than concentrations in order to allow comparison of the element in both metal and gas, and in this case the activities may be regarded as the concentration of element transferred to pure iron at equilbrium.

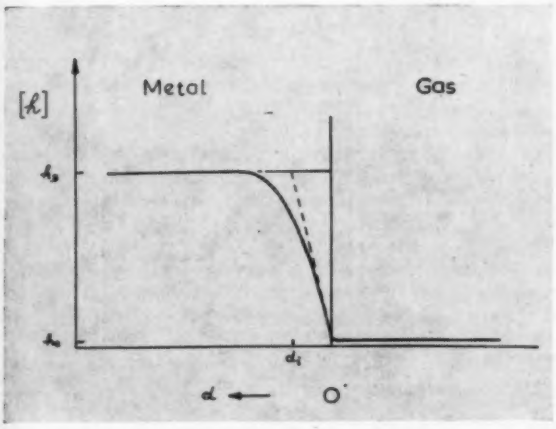

Fig. 3. Schematic representation of the variation in the Henrian activity of a volatile element in the neighbourhood of the free surface of a vacuum melt.

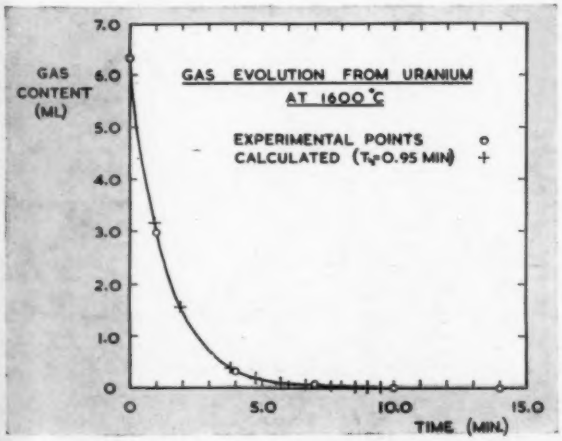

Fig. 4. The progress of gas evolution from uranium during vacuum fusion analysis at 1600°C (data from [8]. Experimental points: o; Calculated points: +. ($T_{\frac{1}{2}}$ taken as 0.95 min.)

The diffusion from the bulk of the metal through the boundary layers to the interface follows Fick's Law:

$$\text{i.e.,}\ \frac{dM}{dt} = D \,.\, A\,\frac{(h_B - h_e)}{d_i}$$

where $\frac{dM}{dt}$ = the rate of mass transfer;
D = the appropriate diffusion coefficient;
A = the interface area;
d_i = the effective interface thickness; and
h_B, h_e = the Henrian activities of the solute in the bulk of the metal and in equilibrium with the gas, respectively.

For gases in metals during vacuum treatment, h_e is substantially equal to zero and the equation reduces to:

$$\text{Rate} = (DA/d_i)h_B$$

This finally reduces to the form of the observed Equation (3), if Henry's law applies; i.e., if h_B = wt.%. Unfortunately, few predictions of reaction rates can be made using this equation, as the values of D and d_i are generally unknown.

In the case of the evaporation of metallic solutes from vacuum melts, h_e is not zero and the rate of loss only follows Equation (3) in the initial stages while $h_B \gg h_e$, and the rate falls off as equilibrium is approached. Table I gives the concentrations of various solute elements in iron in equilibrium with their own vapour at 10^{-5} atm, calculated from available vapour pressure and activity data. As this suggests, magnesium, lead and manganese should be practically eliminated from iron during vacuum melting, and in fact the manganese in a normal charge (*ca.* 0.5%) is reduced to less than 0.01% in a 30-min. vacuum treatment at 10^{-6} atm,[5] while Mg and Pb are below analysis limits.

The rate of loss of solute in first-order processes is such that if the time to reduce the concentration to a half is $T_{\frac{1}{2}}$ (the "half-life"), then the concentration is reduced to $1/2^n$ in n half-lives. Equilibrium is thus substantially reached in 10 half-lives as the concentration is then reduced to less than 0.1% of the initial value. The concept of a half-life is of convenience in the rapid interpretation of experimental rate data, as the time to reduce the initial concentration to a half is an easily determined parameter; e.g., an experimental curve for the evolution of mixed gas (87 wt.% O_2, 12 wt.% N_2) from uranium during vacuum fusion analysis[8] is shown in Fig. 4, and the curve may be compared with points calculated for a half-life of 0.95 min. obtained from the early part of the curve; from this half-life it is clear that measurement beyond 9.5 min. would be unrewarding.

Conclusion

Although thermodynamic considerations in many cases allow the final equilibrium state to be predicted, the physical factors governing the rate of approach to equilibrium are equally important in determining the state of a vacuum melt after a given time of vacuum treatment. Unfortunately, the rates of reaction are generally not calculable and the results of vacuum treatment cannot therefore be predicted with certainty, but comparison of the experimental results with the equilibrium values shows the value of longer treatments or stirring to equilibrium.

‡ This is indeed fortunate as the equilibrium state in a vacuum melting chamber is only reached when the metal has completely evaporated from the crucible on to the chamber walls.

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Fig. 1. Photograph of plant, boiler house in foreground, followed by purification stream.

PRESSURE GASIFICATION AT MORWELL

by R. S. ANDREWS, C.M.G., D.Sc., M.I.Chem.E., F.Inst.F.*

AUSTRALIA was the first country outside of Europe to introduce pressure gasification of coal for town's gas supply. This was considered to be a step towards cheaper gas production and a somewhat revolutionary change from conventional methods by the introduction of more modern techniques. It is well known that this method of gasifying coal, by means of steam and oxygen under pressure, was conceived at Charlottenburg University, in Germany, by Danulat and Hubmann, who were working under the direction of Professor Drawe. Later the process was developed for commercial operation by the Lurgi Gesellschaft-für-Warmetechnik at Frankfurt-am-Main, and plants were subsequently erected at Böhlen and Brüx.

It was decided in 1950 to erect a Lurgi high-pressure gasification plant at Morwell, Victoria. In 1951 it was planned that the plant should come into operation in the spring of 1956, which it did, and was officially declared open on December 5 of that year by His Royal Highness the Duke of Edinburgh. The selection of this type of plant was influenced by the nature and distribution of Australia's coal reserves and the solid-fuel position in the State of Victoria.

Australia's Coal Reserves

These reserves lie mainly in the east and south-east coastal regions of the continent. Fortunately, this area contains the bulk of the population and these conditions are likely to exist for many years to come. The nature and distribution of these reserves are shown in Table I.

From the above table it will be seen that while Queensland and New South Wales have abundant supplies of bituminous coal, the southern state, Victoria, is practically devoid of such material, but possesses vast quantities of brown coal. In the interest of an integrated fuel economy for the country it was considered essential to develop these large resources to the maximum.

Victoria's Brown Coal

Most of the brown coal reserves lie near the surface, in the Latrobe Valley, 100 miles east of the city of Melbourne. These reserves constitute the largest individual and most easily worked deposit in the world. The proximate analysis of the raw coal is shown in Table 2.

The coal is won by open cut mining and was first used for large-scale power generation on the field in 1924. Subsequently, a proportion of the brown coal was briquetted in extrusion presses at approximately 10,000 psi without a binder, to supply the solid-fuel market. The output of briquettes at present is over 600,000 tons a year, but two more factories are now in course of erection the first of which commenced operation in May, 1959. Today raw brown coal is being mined for approximately 7s. a ton. The proximate analysis of the briquettes is shown in Table III.

TABLE I—Australia's Coal Reserves

State	Probable Reserves in Million Tons		
	Bituminous Coal	Brown and Sub-Bituminous Coal	Total
(1)	(2)	(3)	(4)
New South Wales	11,000	500	11,500
Victoria	12	44,000	44,012
Queensland	4,000	53	4,053
South Australia		600	600
Western Australia		1,002	1,002
Tasmania	240	2	242
Total	15,252	46,157	61,409

TABLE II—Proximate Analysis Brown Coal as Mined

	%
Moisture	60.95
Ash	0.85
Volatile matter	20.20
Fixed carbon	18.00

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Fig. 2. Photograph of purification stream, oxygen plant building in the background, and dehydration plant on extreme right

How some engineering problems encountered in the gasification of an Australian brown coal were overcome

Brown Coal Gasification

With this background of brown coal development for power generation, and for general use in industry, it was natural that attention should be directed to its use in gas production. Existing plants in the city of Melbourne were of the conventional type, carbonising and water gas units, and the gas-making coal was transported 800 miles by sea from Newcastle, in New South Wales, to supply the 350,000 gas consumers in the southern capital city.

Owing to brown coal briquettes being available for industry at a lower price than coke, and the fact that brown coal itself is non-caking, it seemed advisable that a process for its complete gasification should be selected. After considerable investigation, the Lurgi high-pressure gasification process was chosen for the purpose.

TABLE III—Proximate Analysis Brown Coal Briquettes

	%
Moisture	13.00
Ash	1.95
Volatile matter	44.68
Fixed carbon	40.37

TABLE IV—Performance Data

Gross calorific value of brown coal briquettes	9695 Btu
Gasification efficiency	81.25%
Yield of purified gas per ton of briquettes ..	36,100 cu. ft.
Oxygen used (95%O_2) per 1000 cu. ft. of gas	177.8 cu. ft.
Steam consumption per 1000 cu. ft. of gas ..	79.76 lb.
Temperature of steam used	412°C
Calorific value of purified gas per cu. ft. ..	445 Btu
Analysis of purified gas produced:	
CO_2	2.0
O_2	0.2
$C H_m$	0.3
CO	21.8
CH_4	19.1
C_2H_6	0.4
H_2	53.9
N_2	2.3

The plant when erected consisted of six Lurgi generators, with requisite cooling and purification units, two brown-coal-fired boilers each with an evaporative capacity of 55,000 lb. an hour and two Linde-Fränkl oxygen units, each capable of liquifying 500,000 cu. ft of air an hour. The generators were designed for an output of 3 million cu. ft per generator a day. They are now operating at an output of 6 million cu. ft per generator a day and higher outputs are expected in the future.

The CO_2 and H_2S are removed from the gas by water washing under pressure. After purification the gas is odourless, and for safety reasons it is odorised by the addition of 0.7 g of tetrahydothiophene per 100 cu. ft. It is then dehydrated by means of triethylene glycol before entering the 103-mile-long 18-in. steel welded pipeline, by which means it is transported to the metropolis.

This plant is now supplying approximately 30% of the gas required by the Gas and Fuel Corporation's industrial and domestic consumers. The plant and pipeline were erected for approximately £A11 million.

Chemical Engineering Problems

It is only natural when new and revolutionary techniques are introduced that unforeseen problems will arise and teething troubles be experienced. The main chemical engineering problems which arose and required solution may be divided into two categories:

(a) grate re-design to meet the peculiarities of the brown coal ash; and
(b) corrosion.

Grate Re-design

It would appear from past experience in fuel technology that it is difficult to forecast the behaviour of coal ash when new techniques are introduced. The grates supplied with the Lurgi generators were not correctly designed for the adequate removal of the ash from Yallourn brown coal. Whilst the percentage of ash in the coal is low, the alkali content (Na_2O and K_2O) is comparatively high, varying from 3.6% to 6.3%. The presence of these compounds has had an influence on grate re-design. The initial construction was a simple flat grate concentric with the generator. There

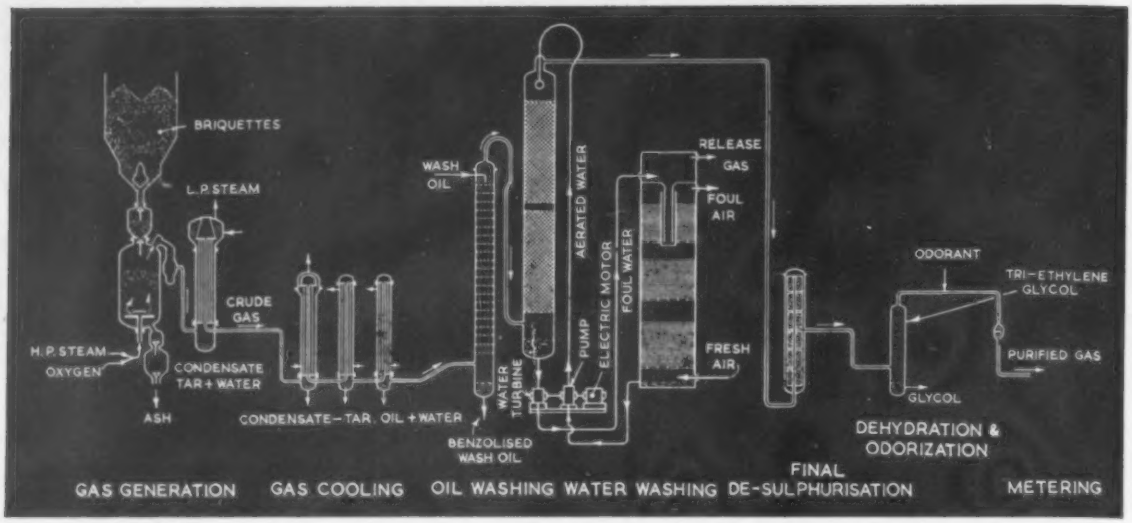

Fig. 3. Flow sheet of Lurgi high-pressure gasification plant at Morwell.

was only one opening for the gasification media, steam and oxygen, which was provided by a cast steel mushroom with a diameter of 890 mm.

During the initial period of operation difficulty was experienced in ash removal, which was due to an excessive amount of moisture in the region of extraction, at the periphery of the generator. This resulted in the cementing and building up of ash against the wall and wearing plates of the generator. It was also accompanied by the leaching of the soluble alkalis from the ash and their concentration in a layer close to the wall. Analyses of lumps of these leached products were found to contain up to 60% to 70% of alkali carbonates and 30% to 40% of alkali hydroxides.

The moisture, which leached the alkali from the ash, was formed by condensation at the periphery in the lower portion of the generator. The presence of alkalis caused serious corrosion of the steel jacket in this part of the generator and, with the exception of one, all steel jackets have been replaced within the two years of operation. The solution to this problem was obvious: namely, to increase the temperature in this portion of the generator and thus prevent condensation, with subsequent leaching and corrosion. Grates with two and three openings for steam and oxygen were designed so as to spread the heat more evenly over the whole of the lower portion of the fuel bed.

A three-opening fabricated top was applied to the original grate in one of the generators in January, 1958. This grate operated for 10 months, during which time no difficulty was experienced in removing ash due to cementing by excessive alkali or clinkering. This type of grate has been improved and installed in other generators, and it is further proposed to install a grate with four openings in one of the generators.

In addition to troubles experienced with ash removal, the cracking of the metal in the grate itself caused concern. It was thought that this was due to too great a concentration of heat when only one opening for the gasification media was provided. With the re-design of the grates and the provision of additional openings, the tendency to cracking of the metal was considerably reduced. The high temperature in the neighbourhood of the grate was accentuated by the very low ash content of the fuel.

Corrosion

Attention was directed to the seriousness of this problem in June, 1957, by the rupture of a gas main at the inlet to one of the waste heat boilers, through which the gas passes immediately after leaving the generator. The steel main had been reduced in thickness from 6.5 mm to 1 mm by corrosion from condensed liquor. All pipework in which condensate was present was thoroughly surveyed by means of:

(a) sentinel drilling;
(b) thickness testing by means of "Radothick"; and
(c) thickness testing by means of "Ultrasonic Tester"

All pipework found to have suffered corrosion was replaced. In none of the five Lurgi plants operating overseas was corrosion by gas condensate experienced. The *p*H of their condensates ranged from 8.5 to 9, whilst the *p*H of these liquors from the Morwell plant were from 5.5 to 6. The reason for this was the low ammonia content of the condensate due to the brown coal possessing the lowest nitrogen content of any coal known, so far as could be ascertained. For the rectification of these adverse conditions condensate with a higher ammonia content (*p*H = 9) collected from the gas coolers was injected into the spray cooler circulating system prior to the waste heat boilers. In addition, to reduce velocity of condensate flow and prevent condensate impingement, certain portions of the pipework were re-designed. As a result of these steps, the corrosion rate has been reduced from 0.087 in. a month to 0.007 in. a month. Investigations are proceeding to reduce this corrosion still further.

While these two major problems of satisfactory grate design and elimination of corrosion are as yet not completely solved, their nature is understood and considerable progress has been made towards their complete solution. The plant is now operating with comparative smoothness and there is an atmosphere of confidence regarding the future of this method of gasification.

Nature of By-products

The two main by-products are tar and benzole, the yield being 10 gal. and 3 gal. respectively per ton of briquettes. The nature of these products, however, is unusual. The tar, while rich in phenolic compounds, is largely paraffinoid in nature, waxes being the main constituents of the heavier fractions. The tar is distilled, being fractionated into the lighter oils, or benzole, and a wash oil for scrubbing the benzole from the gas. The heavy waxy residue is thinned

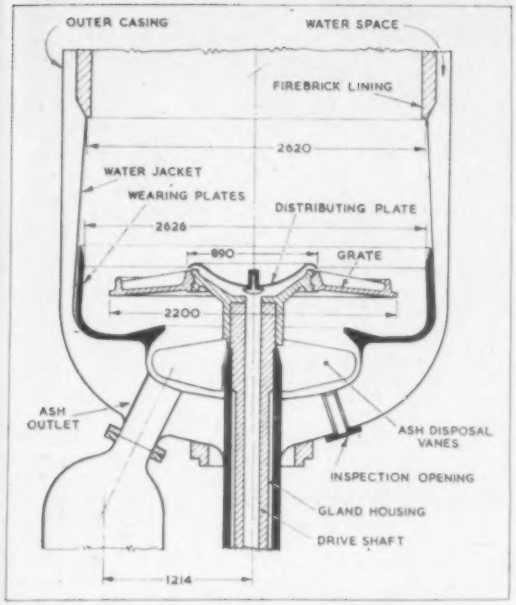

Fig. 4. Diagram of original Lurgi design grate.

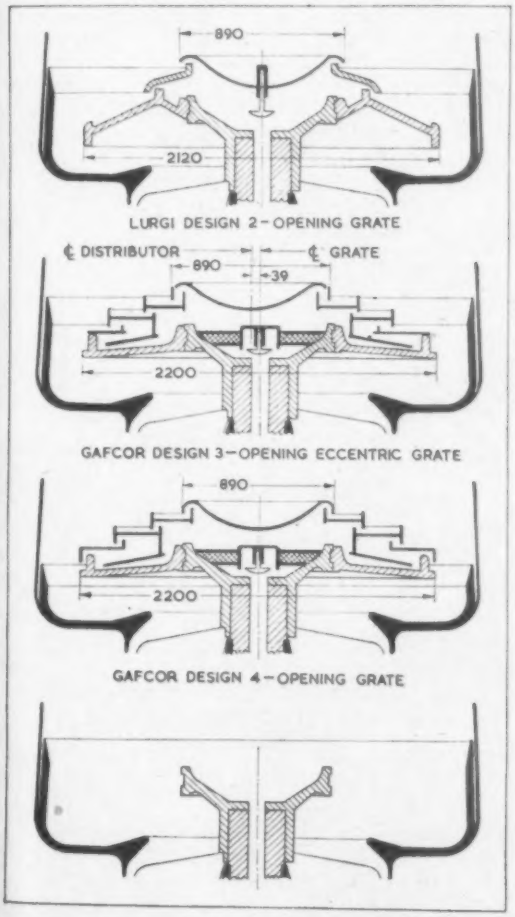

Fig. 5. Diagram showing modified designs of grates. The three-opening eccentric grate has proved to be the most successful design. (Dimensions are in cm.)

with light oil and used as a priming medium in road construction.

Arrangements are now in progress for the recovery of phenols, cresols and xylenols from the wash oil distillate and effluent liquor. The constitution of the benzole is approximately 60% aromatic hydrocarbons and 40% unsaturated compounds. At present this product is being sold to an oil refinery for rectification, but a Benzoraffin plant is on order to refine this spirit by vapour phase hydrogenation with Lurgi gas at 35 atm using a molybdenum catalyst.

These are the true by-products incidental to the manufacture of gas by this process and whose quantities in production cannot be controlled. It may be of interest now to consider the synthetic production of materials from gaseous constituents whose quantities can be controlled.

Production of Synthetic Liquid Fuel

This chemical engineering project at Morwell is producing the cheapest hydrogen, carbon monoxide, carbon dioxide and nitrogen in the country. This naturally suggests the production of synethic materials, such as ammonia, urea, methanol or liquid hydrocarbons.

One of the greatest problems which the gas industry has to face is the economic factor resulting from the difference between the winter and summer loads. Costly plant remains unproductive during the greater portion of the year. It is now being realised that a contribution could be made to lower gas production costs if seasonal idle plant could be utilised and the gas produced used for the production of synthetic products.

In a country like Australia, where oil in payable quantities has not yet been discovered, and which is dependent entirely upon imported petroleum to meet its needs in industry, agriculture and transport, liquid fuel synthesis would appear to be the answer. With this objective in view, close contact has been maintained between technical officers of the Gas & Fuel Corporation and those engaged in work on Fischer-Tropsch synthesis in Great Britain, the U.S.A. and Germany and with those operating the large-scale synthesis plant at Sasolburg in the Union of South Africa.

The result of our investigation indicates that for economic production of synthetic liquid fuel gas would have to be produced at approximately the same price per therm as the present market price of crude oil. With existing gasification processes this can only be accomplished if the coal price is 10s. a ton or lower. When gasification processes now in course of development, which involve the use of plant of low capital cost and of high capacity, come into commercial operation, low raw material costs will not be so vital.

Although raw brown coal is mined in the Latrobe Valley for 7s. a ton, it possesses a moisture content of 60% and when dried to the requisite moisture content (25%) and screened the cost is higher than £1 a ton.

Preliminary calculations have been made regarding gasification of raw brown coal in a producer, under pressure and using air, whereby the inherent moisture content is used as a gasifying medium instead of steam from an outside source. Before such techniques were brought to the development stage it was first necessary to study the Fischer-Tropsch synthesis when using a gas rich in nitrogen.

For this purpose a small unit has been installed, similar to a United States Bureau of Mines catalyst test apparatus. Brown coal gas from the Lurgi plant, diluted with nitrogen to the requisite percentage, is being used as the synthesis gas. The small unit operates at a pressure of 300 psi and within a temperature range of 250-300°C. The gas flows at the rate of 5 cfh through an iron catalyst. By varying conditions under which the synthesis is carried out, the proportion of tail gas to liquid products can be varied over a wide range.

The economic combination of town's gas manufacture

and synthetic liquid fuel production not only solves the problem of surplus summer plant capacity, but provides a country, devoid of natural oil, with some degree of security in vital liquid fuel supplies. It may be advantageous to pursue this idea in relation to possible future developments.

Gas Production of the Future—A Chemical Engineering Problem

For over 150 years the conventional method of town's gas manufacture has been by the carbonisation of caking coals accompanied by the production of coke and tar. With the dawn of the present century water gas practice was introduced for the purpose of meeting peak loads, fluctuating demands and stabilising the coke market. In 1940 large-scale pressure gasification of non-caking coals with steam and oxygen was first introduced at Böhlen near Leipzig.

The introduction of pressure gasification by the Lurgi-Gesellschaft, using a static fuel bed, marked a revolutionary advance in gasification technique. It made a process available for the use of non-caking and slightly caking coals, which are generally speaking cheaper and in more plentiful supply than gas-making coals. Furthermore, it is the cheapest method of town's gas production so far developed, provided the capacity is above the economic minimum. In Australia this capacity would be in the region of 25 million cu. ft a day.

There seems little doubt that pressure gasification has come to stay. It has many advantages over the conventional methods, other than those which have been mentioned, one of which is higher output per square foot of grate area.

One of the main advantages is in gas distribution. As the gas is produced under pressure no costly boosting is required and plants can be erected on the coal fields, even though remote from areas of consumption. With gas under pressure, feeder mains can be used in the reticulation system which can give better and cheaper supply in expanding areas.

The advantages of pressure gasification as it exists today may be summarised as follows:

(a) cheaper gas production if plant output is sufficiently high;
(b) gasification of a greater range of cheaper coals than by conventional methods;
(c) complete gasification of coal, thus economics not dependent upon an uncertain coke market;
(d) gas is already under pressure, of which advantage can be taken to reduce distribution costs; and
(e) as gas is purified under pressure the quantity of deleterious compounds, which normally occur in coal gas are considerably reduced. In the gas from the Morwell brown coal organic sulphur and gum-forming compounds are almost entirely absent.

It is probably these factors which persuaded the Gas Council to give favourable consideration to the introduction of pressure gasification into Great Britain.

High-pressure techniques and air liquefaction have broken through the crust of conventional conservatism in gas manufacture requiring the services of chemical engineers.

The question now may well be asked what lies over the horizons for the gas idustry tomorrow? The use of natural gas in vast quantities, coupled with its cheapness, suitability and convenience, in the United States and the part which it has played in the fuel economy of that country could very well set the pattern for chemical engineering projects in this field for the future.

In our modern civilisation, however, there are certain spheres in which gas is preferred to either oil or a solid fuel.

The United States is extremely fortunate to possess immense wealth of natural fuels in the form of coal, oil and natural gas. Other countries, such as Great Britain and Australia, for example, are not so fortunate. They have to depend for nearly 30% of their total energy requirements on oil from the Middle Eeast. All may be well provided that the free geographical distribution of oil is always permitted, but can this be guaranteed? Surely security in this connection is a problem for the chemical engineer.

The solution would be to produce from coal a gas for appoximately 3s./1000 cu. ft at the source of production. At this price, gas could compete with oil in many forms of usage in industry; synthetic liquid fuel could be synthesised from the gas at a price comparable with the natural product; and in the domestic field gas could supply all those fluctuating demands and peak loads which are uneconomical for electricity.

The idea that the use of gas is old fashioned and that it is modern to use electricity must, in the national interest, be abandoned. It should be the aim so to balance gas production and electricity generation; the former to be used for as many purposes for heating as possible and the latter for power. This can only be accomplished if gas production costs are substantially reduced.

This contribution to our national fuel economy and security can be achieved by chemical engineers who assist in the development of the high capacity plant, of low capital cost, which will be required for the purpose. This may be done by the development of gasification units, operating at 30 atm pressure and gasifying coal in a pulverised state with steam and oxygen at temperatures above the fusion point of the ash. Such plants are now in course of development. In this field much responsibility will rest with chemical engineers.

Conclusion

In this brief survey the introduction of pressure gasification of coal has been featured and the possibilities indicated which gas could play in our national economy and security. Surveys indicate that the known reserves of coal are approximately 30 times (in Btu) the known reserves of oil. Admittedly, the known reserves of oil can be misleading, as only the future can disclose the quantity which may yet be discovered. Nevertheless, human needs cannot rely upon possibilities, but rather on what is known. The standard of living and security of many parts of the Western world are dependent upon ample liquid fuel supplies or their equivalent.

It seems to be inevitable that just as atomic power will supplement power generated from coal, cheap gas and synthetic liquid fuel will supplement what may be dwindling supplies of natural oil. To depend entirely upon future discoveries of oil and the certainty of continued free geographical distribution, when 65% of the world's supplies come from the Middle East, would appear to be unwise.

When considering the vital energy requirements of the latter part of this century, it is obvious that chemical engineers must play a major part. The national developments in coal processing require their services just as much as the oil and chemical industries.

It has been the tendency in Australia for chemical engineers to prefer work connected with design, research and development, but it would seem equally important that they should play their part in production. Many seem to feel that in the field of production much of their time is taken in administration and the handling of labour and that there is not the scope to use their training to maximum advantage. Many chemical engineers could make a greater contribution to planning, design, research and development if they first had adequate production experience. By this means they would see their problems in a truer perspective.

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THE CHEMICAL PLANT CONTRACTOR AND THE MANUFACTURER

PART III*

A discussion of the problem of releasing commercially valuable information during the execution of a project

by M. DAVIDMANN, B.Sc.†

Disclosure of Know-how

THE manufacturer is concerned with maintaining and improving his competitive position relative to other suppliers of the same or of competitive products. He is likely to originate process improvements which result in a cheaper or a better product. His research department is looking for new outlets and may find new products and methods of making them. He may, for a substantial fee, obtain a licence to produce a given product. His income depends on his output and price in relation to demand and his competitor's output and price. Hence his process data and process improvements constitute his stock-in-trade, his know-how, not to be disclosed to present or potential competitors unless they are penalised by a licensing fee.

The manufacturer is not alone in encountering competition. The contractor also is concerned with maintaining his competitive position; in this case, that relative to other contractors. His research department is searching for new processes and how to improve existing processes. He may own and acquire process data, obtained at some considerable cost to himself. Given effective mechanical design, fabrication, procurement and erection, that is, given that construction is carried out effectively, his income depends on his chemical engineering design data and methods, and on his processes and process data.

Difficulties clearly arise when manufacturer and contractor jointly take a process from research through design to producing plant. The contractor may later on offer suitable plant to the manufacturer's present or potential competitors, or he may use process information gained during the course of the contract to the manufacturer's disadvantage by disclosing it to the manufacturer's competitors. The same difficulties arise whenever a plant is provided by a contractor to a manufacturer.

In the same way the manufacturer may disclose the contractor's know-how to the contractor's competitors when asking for tenders for, or when buying, another similar plant from another contractor, or by publishing test results together with design information.

A similar situation exists when an independent research organisation is employed. Here the danger is that work paid for by one customer may be sold a second time to another at greatly increased profit, the work having been paid for already by the first customer.

It is for reasons such as these given here that the manufacturer prefers to have his plants designed and installed, or modified, by his own engineering organisation.

The disclosure of know-how to competitors is shown in Fig. 12. The field of activity on which it is based is that of Fig. 10 (see page 336, May issue) and the diagonal lines represent competing contractors and competing manufacturers. It applies as well to manufacturers and contractors as to manufacturers and constructors. The division of work for the particular contract illustrated is such that it occurs between functions 1 and 2, this defining the type of contract on the field.

Know-how

Know-how is correlated, recorded and applied experience. Suppose that a manufacturer finds that specific materials of construction are required to obtain a reasonable working life from a given type of valve on a particular process stream. Suppose also that he orders such valves, stating both the process stream and the materials of construction. It is then possible that the supplier who provided the valves in due course offers valves suitable for this particular process stream to chemical industry at large. The open sale of these valves, incorporating the specific materials, may amount to a disclosure of know-how to the manufacturer's competitors.

If the valve supplier guaranteed the first set of valves, which failed consistently, as suitable for their purpose, and then continued to replace them at his own cost until satisfactory materials had been found, then the know-how would belong to the valve supplier, irrespective of losses incurred by the manufacturer as a result of interrupted production. The supplier could then offer his valves to anyone, as proved suitable for this particular process stream.

Should the manufacturer require further valves, the know-how belonging to the supplier, the manufacturer should not disclose it to the supplier's competitors when calling for quotations. The manufacturer should call for quotations without disclosing the materials, and in deciding with whom to place the order should weigh his knowledge that this supplier's valves are proved against guarantees given by his competitors. When the supplier guarantees the valves as suitable for the particular process, he need not disclose the materials of construction he is supplying.

Should the replacement costs have been paid by the

* Parts 1 and 2 were published in the April 1960 issue (page 264) and the May 1960 issue (page 335) respectively.

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manufacturer, then the know-how belongs to him and it may not be used by the supplier. Should the supplier receive an inquiry from a prospective customer for a valve suitable for the same, or a similar, process stream, he should offer a valve made up from his standard materials of construction, leaving it to his prospective customer to decide whether these valves are suitable or not. Even his ability to supply the specific alternative materials should not be disclosed, but he may state that any other alternative materials could be supplied at extra cost and at customer's request. In short, the choice of materials should be left entirely to the prospective customer.

On the other hand, the valve supplier may approach the manufacturer whose know-how he would like to use, disclose the prospective customer, and obtain agreement to use the special materials of construction so as to guarantee his valves suitable for the particular process stream. The manufacturer may agree and charge a fee. This fee would, in effect, be paid by the supplier's customer to the manufacturer. It therefore suffers from all the disadvantages given later in this article for such a case.

The valve supplier thus has to put forward standard materials of construction, as stated in his quotation, leaving it to his customer to specify special materials or other special requirements. He may, of course, introduce the prospective customer to the experienced manufacturer, if both parties agree to this, leaving them to sell or license know-how to each other.

In each case one can decide to whom know-how, that is experience, belongs, not only for the simple example given here but whenever process and plant meet, that is, whenever contractor and manufacturer come together. The ownership of know-how should be clearly defined in each contract, design know-how belonging to the contractor and process know-how belonging to the manufacturer. Any one party may not disclose the second party's know-how to a third. The manufacturer should not disclose design know-how; the contractor should not disclose process know-how.

Where the customer requires information to enable him to carry out maintenance work, the disclosure of information should be restricted to the minimum, spare parts being obtained from the contractor at the contractor's discretion, drawings and design remaining the contractor's property.

Know-how is of value to the recipient only if he uses it, and such use cannot but be detrimental to the interests of the contractor who supplied the information in the first place. It follows that the contractor should refuse to disclose design information to the customer. In general, each drawing should clearly specify the ownership of the information it contains with respect to process, chemical engineering and mechanical design information.

Licensing

In general it is the manufacturer who develops, improves and patents processes. He may then offer these, under licence, to contractors. The contractor may have to pay a fee so as to obtain only an option to enable him, at considerable cost, to acquaint himself with the process, in order to decide whether he wishes to take out a licence. Should he decide to take up the process, he obtains the licence at additional cost. Both the option and the licence are likely to contain secrecy clauses. The contractor, now a licensee, proceeds to advertise so as to obtain inquiries in order to sell the specific plants in which this process is carried out. It will cost the contractor a considerable amount of money to prepare quotations for the various manufacturers who may be interested. Assuming that the contractor obtains an order, he may then have to pay a further fee to the manufacturer who originated the process or process improvement, that is, to the licensor. This fee may be based on the number and size of plants sold.

If the licensor has patented the process, a good deal of the process know-how is contained in the patent. In any case, the contractor is likely to obtain only process know-how from the licensor, having to contribute his own design knowledge and experience. Any design data disclosed by the licensor is likely to be based on the plant in which the process is being carried out at the licensor's works and would thus belong to the contractor who designed the plant in the first place. Any fee for design data should thus be paid to the contractor who designed the plant and not to the licensor. Indeed, such design data should not be disclosed by a manufacturer without the agreement of the contractor who designed the plant.

When a process is offered to a contractor at the laboratory stage, by a manufacturer, there is no doubt that the contractor has to contribute design know-how before a plant can be provided.

A manufacturer would be interested in selling licences for a particular process to as many contractors as possible, to obtain the highest income. A contractor would prefer to restrict the number of licensees so as to restrict competition in order to obtain a reasonable return from the money he has invested in taking out the licence.

When a contractor takes out a process licence, the sequence of events is then as follows:

(1) A manufacturer invents or improves a process. Licences are offered to contractors for building plants for carrying out the specific process.
(2) The contractor pays the manufacturer a fee, for an option to take out a licence, to enable him to investigate the process.
(3) The contractor evaluates the process at considerable cost to himself. He receives process data, but has to contribute design know-how.
(4) Deciding that this process is more economic, or results in a better product than others, from the point of view of his prospective customers, or that there is a need for the process, the contractor takes out a licence, agreeing to pay the licensor further fees in accordance with, say, the number and size of plants ordered. Other contractors will obtain licences for the same process at similar cost to themselves.
(5) The contractor now submits quotations to prospective customers for plants in which this process is carried out. Each quotation can cost the contractor a good deal of money.
(6) The prospective customer, another manufacturer, who is concerned about using the most economic process, chooses between alternative processes on the basis of quotations received from a number of contractors.
(7) Let us assume the licensee receives an order. His price includes the fees he has had, and still has, to pay to the licensor, and the cost of previous unsuccessful quotations to other prospective customers, who are also manufacturers.

The sum total of points (1) to (7) above is that a manufacturer has invented or improved a process and has licensed this, by a very circuitous route, to another manufacturer. The contractor invests money in evaluating a process which, in the end, he may decide not to take up. He invests more money when he takes out a licence and still more money while he quotes to interested manufacturers. The licensor cannot lose, the prospective customer receives free advice on particular processes in the form of technical discussions with, and quotations from, contractors. The contractor risks his money and the manufacturer who orders a plant pays for quotations prepared for other manufacturers.

From the manufacturer's point of view:

(a) A process is licensed by one manufacturer to another.
(b) Manufacturers evaluate alternative processes on the basis of quotations received from contractors.

(c) A manufacturer places an order for a plant in which the preferred process is carried out, on the basis of competitive quotations received from contractors.

One fails to see why contractors should take any risk whatsoever as regards item (a) and why the contractor provides a free process advisory service in connection with item (b). A manufacturer may at the moment ask contractors to do work costing £1000 for the possibility of saving £100. Further, a manufacturer who places an order pays for advice given to other manufacturers who may even be his competitors.

We saw earlier on that two relationships exist between contractor and manufacturer: namely, an advisory and a contractual relationship. These correspond to items (b) and (c) above, respectively, the unsuccessful contractors [item (c)] remaining in the advisory relationship.

The contractor thus offers two distinct and separate services. The first is advisory and assists the manufacturer in selecting the most suitable process for that particular manufacturer's special needs, as the manufacturer cannot do this without quotations. The second is the provision of plants. Hence we conclude:

(1) Processes are the concern of manufacturers, and of manufacturers only.

(2) Processes should be licensed by one manufacturer to another. The contractor who investigates a process at his own cost, or who takes out a process licence at his own cost, is taking a risk which is clearly one which only the manufacturer should take.

(3) No fees should be paid by contractor to manufacturer for process information. Such fees should be paid only by one manufacturer to another.

(4) The contractor who advises in the form of technical discussions and quotations in connection with processes—in other words, who assists the manufacturer in selecting one process rather than another—is offering a specialist service, quite distinct from that of plant contracting, and should be paid for his work in this connection. The manufacturer who receives the advice should pay and not the customer who orders a plant. This means that a fee should be paid for each quotation, being paid by the manufacturer to the contractor, and by the contractor to the subcontractor.

Contractor's Process Activities

Contractors provide plants for processes for which they have taken out a licence, or of which they have experience, or which are generally available. At times the contractor carries out process research, at least in so far as he evaluates processes so as to decide whether to apply for a licence to supply plants in which a particular process takes place.

The manufacturer chooses the product he intends to market, its form and shape as well as its quality, and the raw material. He decides the size of plant to be installed and the degree of continuity of operation, i.e., the standby facilities, he requires. This is the manufacturer's process definition.

A number of alternative processes may appear attractive or be available and the manufacturer has to compare them before he can decide on one or the other. The manufacturer bases his decision on the cost of the product, allowing for capital and operating costs, in the prevailing or anticipated circumstances. He thus calls for quotations from a number of contractors to evaluate alternative processes.

Contractors who do not realise that processes are a matter concerning their customers rather than themselves tend to regard know-how as consisting of process experience. As long as a contractor concentrates his attention on processes rather than on plant design, it is unlikely that he can bring to bear on any particular process the design experience gained on other processes. The division of his design work into specialist sections concerned with processes underlines the manufacturer's concern about his know-how being disclosed to his competitors by the contractor. The contractor's chemical engineers, now called process designers, are not likely to have the time, nor is it their responsibility, to accumulate and correlate knowledge and experience concerned with any particular unit operation. From the point of view of chemical engineering design, the contractor's experience on any particular unit operation is then scattered throughout process files. Process know-how is likely to be developed at the expense of chemical engineering design know-how.

The contractor who provides unit plants for one or two operations, and plants for one or two treatments, is likely to do this effectively. His equipment and plants (for example, direct coolers, scrubbers and driers) are comparatively uncomplicated. He supplies these to chemical industry at large, irrespective of process.

The somewhat larger contractor, once he divides his work according to processes, feels the limitations. In due course he is likely to lose his lead in design know-how but his knowledge of particular processes increases. As there are very many processes, he may in due course supply but a few of the plants required for carrying out processes in general, concentrating on supplying particular branches of the chemical industry. His preoccupation with processes may thus limit his activities to the processes of which he has experience or for which he can obtain a licence.

In due course he expands his process activities, at the expense of his design know-how, until he ceases to be competitive in designing, fabricating and providing the unit plants and plants for single treatments in which he specialised initially. This, then, may result in the creation of the so-called contractor who is entirely concerned with process evaluation, his plants being designed and provided by subcontractors. This is not a contracting organisation, but one which investigates, recommends and sells particular processes. It provides a specialist advisory service to those manufacturers who need advice on available processes and how they compare with one another.

The smaller contractor is concerned with equipment and plants in which unit operations and single treatments take place. These he provides to the chemical industry at large, irrespective of process. As the contractor grows and tackles larger projects, he finds that a larger number of specialists have to work together and that team-work is ineffective. This is perhaps recognised, but instead of organising so as to obtain effective team-work the design work is divided according to the requirements of different customers, that is, according to processes. This obscures the functional division of work between manufacturer and contractor, and a manufacturer may now consider that any process information he discloses is likely to find its way to his competitors, and he may consequently begin to provide his own plants. The contractor, preoccupied with process rather than with plant design, limits his field of activity to comparatively few processes and the quality of his design work suffers. As he grows still further he ends up by providing an unpaid and limited process advisory service to manufacturers, making a living by buying and reselling plants.

To improve this situation the contractor should clearly differentiate between the process and the plant. His function is to provide plants and his work is characterised by chemical engineering design work. This design work should be subdivided into separate work units, each of which is responsible for work on one particular unit operation. The work is then divided functionally and plants are designed by teams. He may then provide unit plants and plants made up of many unit plants, competing with other contractors in each case. The contractor should expand not by concerning himself with processes, but by extending his activity in the unit operations he already knows and into other types of

unit operations. He should provide plants which include his own unit plants and those of sub-contractors, the plants being provided irrespective of process.

The contractor's activity appears then to be limited, as far as this analysis is concerned, only by the extent to which he can organise his work effectively so as to remain competitive despite the size of his organisation, and by the extent to which his organisation achieves team-work between specialists. The main problem in the provision of major plants, at present, is perhaps that of obtaining team-work. Problems in organisation,[6] in functional division of work and in obtaining team-work,[7] as well as in work planning,[7] are discussed elsewhere.

The Environment

In an industrial civilisation many needs arise for a large number of different products and services. These needs are satisfied by a correspondingly large number of specialised work units. Competition between work units ensures that needs are satisfied effectively. Individuals and work units work in harmony together to satisfy the society's needs.

This system of organisation, in which reward is in proportion to the urgency of the need satisfied, and to the service rendered, will succeed in meeting the society's needs only if all the following requirements are satisfied:

(1) The society's effort has to be divided into separate and distinct activities carried out in work units. Each work unit carries out an activity essential to the completion of the work, determined by the work undertaken. This division of work, to be effective, has to be functional.
(2) Free competition is required between work units carrying out the same functional activity.
(3) Individuals and work units need to co-operate with each othe to complete the work undertaken.

If any one of these requirements is not met, then difficulties can be expected. For example, to enable a work unit to operate, not only has the work to be done, but capital is required in addition. Shareholders and employees thus form a team, co-operating with each other in the carrying out of the work unit's task. When the work unit is a company, then it is the responsibility of the board of directors to ensure that shareholders' and employees' respective responsibilities, and the functional relationships between them, are clearly defined and understood, and to apportion reward between shareholders and employees, taking into account the total situation as it is seen at the time. It is not enough for this apportioning of reward to be fair, it must also appear to be fair; that is, those concerned have to understand that it is fair. Where responsibilities, or functional relationships, or fairness of reward are not clearly defined and understood, conflict results between those who should be working together.

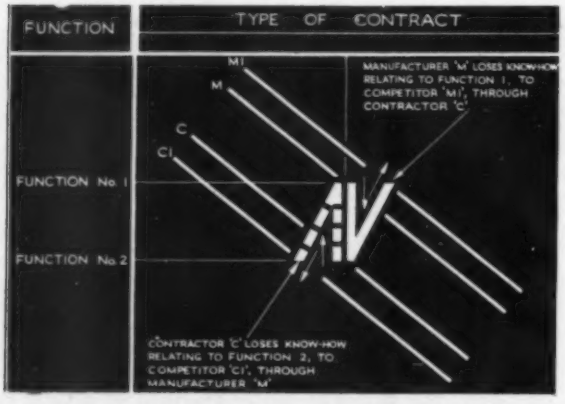
FUNCTION
TYPE OF CONTRACT
M1
M
C
C1
MANUFACTURER 'M' LOSES KNOW-HOW RELATING TO FUNCTION 1, TO COMPETITOR 'M1', THROUGH CONTRACTOR 'C'
FUNCTION No. 1
FUNCTION No. 2
CONTRACTOR 'C' LOSES KNOW-HOW RELATING TO FUNCTION 2, TO COMPETITOR 'C1', THROUGH MANUFACTURER 'M'

Fig. 12. Disclosure of know-how to competitors.

Processes and plants are the concern of manufacturers and contractors respectively. However, the manufacturer provides plants and the contractor concerns himself with processes so that to that extent we see conflicting interests instead of team-work.

It seems that a useful purpose could be served by a code of practice, concerning, for example, know-how and its disclosure, prepared by representative bodies such as the Association of British Chemical Manufacturers and the British Chemical Plant Manufacturers Association, each for their own part of the industry and then jointly for the industry as a whole, initially at a national, and then at an international level. Another point that could be taken up in a similar manner, and of at least the same importance, is that a fee should be paid for each quotation by the recipient. Such representative bodies, agreeing and acting jointly, accept responsibility for the industry as a whole in very much the same way in which, in the previous example, responsibility is accepted by a board of directors.

Conclusions and Recommendations

The contractor carries out chemical engineering design and provides plants, the manufacturer produces, and this would be a functional division of work. However, manufacturers also provide their own plants and contractors are concerned with manufacturing processes. This results in conflicting interests instead of team-work and in plants not being provided effectively. Hence to that extent the manufacturer does not produce effectively.

Processes should be licensed by one manufacturer to another and not to a contractor. No fee should be paid by contractor to manufacturer for process information, as such fees should be paid by one manufacturer to another.

As regards any inquiry or contract, process improvements should belong to the manufacturer, design or plant improvements to the contractor. Manufacturers should, as a rule, report useful results to the contractor.

The contractor commissions the plant, but it is the manufacturer who should test and prove it. The contractor should be paid when assisting in testing and proving.

The contractor not only provides plants, but in addition advises in connection with manufacturing processes, by means of technical discussions and in the form of quotations. He should be paid for his work in this connection. The manufacturer who receives the advice should pay instead of the manufacturer who places an order. This means that a fee should be paid for each quotation, by manufacturer to contractor, and by contractor to sub-contractor.

Contractors appear to have experienced difficulties in obtaining team-work between specialists when designing plants of some complexity and have consequently divided their work according to processes. This limits their activity to but a part of the chemical industry. The contractor should divide his chemical engineering design work, functionally, according to unit operations, plants being designed by teams irrespective of the processes which take place. He then has to organise so as to ensure team-work and so that the work is done effectively. His field of activity is then limited only by the extent to which this is done successfully.

Finally, a code of practice, for the industry as a whole, would serve a useful purpose.

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CRYSTALLISATION OF WATER BY UNIDIRECTIONAL COOLING

A series of experiments using salts in water, water alone and on benzene are described

by Prof. P. M. HEERTJES* and Dr. Ir. ONG TJING GIE†

IN the literature on crystallisation there is little to be found on the influence of the heat evolved in this process. Since the heat effects, formation and transportation might well be one of the controlling factors in the crystallisation process,[1] it seemed useful to investigate the relation between rate of crystallisation and rate of heat transfer. For this purpose, a method was used which allowed the crystallisation for unidirectional heat flow to be studied, whereby the crystal formation is on the cooled wall only. Experiments were finally carried out with solutions of salts in water, but a series of experiments on the solvent alone, viz., water, and some on benzene have preceded this work. The results of these experiments are described in this paper.

Kost,[2] who also used undirectional heat flow to study the interface temperature ice-water, has reported that when the main bulk of the liquid is kept at the melting temperature the liquid at the interface is undercooled. The degree

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Symbols Used

a = diffusivity $\frac{\lambda}{cp \cdot \rho}$, cm² sec.⁻¹;
b = increase of K, %;
B_1, B_2 = factors, °C;
c = constant, no dimension;
c' = factor: h/δ^{3d-1}, —;
c_p = specific heat at constant pressure, cal g^{-1} sec.⁻¹;
d = exponent, no dimension;
f = distance from plate, cm;
g = acceleration of gravity, cm sec.⁻²;
Gr = Grashof number: $g\delta^3\alpha\ (T_{20} - T_s)\ \rho_2^2/\eta_2^2$, no dimension;
h = partial coefficient of heat transfer, cal cm⁻² sec.⁻¹ °C⁻¹;
K = proportionality factor, cm² sec.⁻¹;
L = heat of crystallisation, cal g^{-1};
Nu = Nusselt number $h\delta/\lambda$, no dimension;
$p = \lambda_1 (T_s - T_{10})/L\rho_1$, cm² sec.⁻¹;
Pr = Prandtl number $c_p\ \eta/\lambda$, no dimension;
$q = -r^{-2}\ (2.3 \log (1 - r) + r)$, no dimension;
$r = \epsilon/\epsilon_\infty$, no dimension;
T = temperature, °C;
T_s = melting point, °C;
α = coefficient of cubic expansion of water, °C⁻¹;
β = factor, no dimension;
δ = thickness of liquid layer, cm;
ϵ = thickness of crystal layer, cm;
ϵ_∞ = thickness of crystal layer at infinite time, cm;
λ = thermal conductivity, cal cm⁻² sec.⁻¹ $\left(\frac{°C}{cm}\right)^{-1}$;
ρ = density, g cm⁻³;
η = viscosity, g cm⁻¹ sec.⁻¹; and
θ = time, sec.;

The index 1 refers to the crystal layer; the index 2 to the liquid layer.

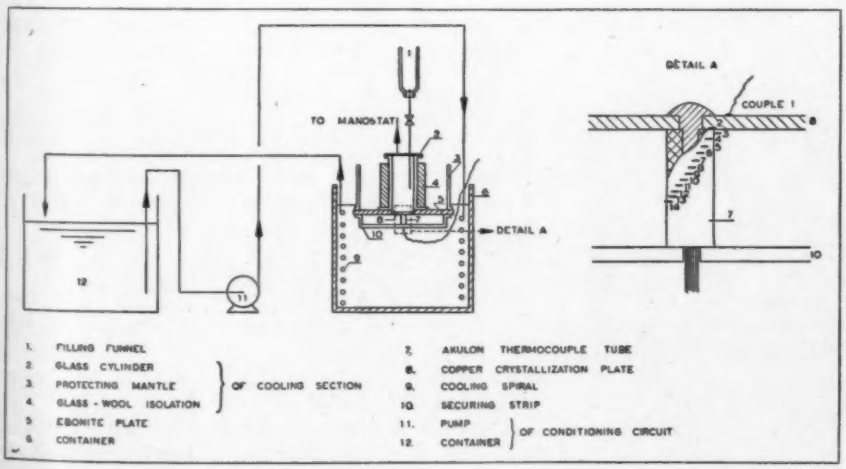

Fig. 1. The complete crystallisation apparatus showing its component parts as used by the authors in the pursuit of their experiments.

of undercooling increases with increasing rate of cooling.[3] Moreover, it has been shown[4, 5] that unidirectional heat flow causes an orientation of the crystals formed; ice, for example, crystallises with the long axis perpendicular to the plane of cooling. The convective movements in the water, caused by density differences, promote this orientation.[6, 7]

Theory

In the experiments to be described cooling is effected by bringing the cooling plane suddenly to the desired low temperature ($T_{1,0} < T_s$, the melting point of the substance) and by keeping the plane at this temperature during the experiments. The theory used in evaluating the experiments has therefore been based upon the papers of Neumann[8] and Stefan.[9]

In the three cases considered below, it is assumed that *no* undercooling takes place at the interface crystal-liquid and, moreover, that for each stagnant layer the thermal conductivity, the specific heat and the density do not change over the temperature range involved.

A. *The Liquid is at its Melting Point* T_s

In this case only the crystal layer need be considered, Let the distance from the cooling surface be x, the temperature T, both measured opposite to the direction of heat flow, and the thickness of the crystal layer at time θ be ϵ.

Integration of the Fourier equation:

$$\frac{\delta T_1}{\delta \theta} = a_1 \frac{\delta^2 T_1}{\delta x^2} \qquad \ldots.(1)$$

using the boundary conditions: (a) $x = 0$, $T_1 = T_{10}$; (b) $x = \epsilon$, $T_1 = T_s$; (c) $\lambda_1 \left(\frac{\delta T_1}{\delta x}\right)_{x=\epsilon} = L\rho_1 \frac{\delta \epsilon}{\delta \theta}$ and assuming that crystallisation starts at time zero, leads to:

$$\frac{T_s - T_1}{T_s - T_{10}} = 1 - \frac{\operatorname{erf} \frac{x}{2\sqrt{a_1\theta}}}{\operatorname{erf}(\beta)} \qquad \ldots.(2)$$

In Equation (2) β is defined by:

$$\frac{L}{(T_s - T_{10})(c_p)_1} = \frac{e^{-\beta^2}}{\beta \cdot \sqrt{\pi} \cdot \operatorname{erf}(\beta)} \qquad \ldots.(3)$$

In the experiments to be described, the value of β was small compared with unity ($\sim$0.25). In this case it is a fair approximation to replace the right-hand side of Equation (3) by $\frac{1}{2\beta^2}$ as can be shown by developing the e powers into a series. Therefore:

$$\frac{L}{(T_s - T_{10})(c_p)_1} = \frac{1}{2\beta^2} \qquad \ldots.(3a)$$

For the crystallisation front $x = \epsilon$, $T_1 = T_s$ (see above); therefore, from Equation (2):

$$\operatorname{erf} \frac{\epsilon}{2\sqrt{a_1\theta}} = \operatorname{erf}(\beta) \qquad \ldots.(4)$$

from which:

$$\epsilon^2 = 4a_1\beta^2\theta \qquad \ldots.(5)$$

Combination of Equations (3a) and (5) gives:

$$\theta = \frac{L}{2(T_s - T_{10})} \cdot \frac{\rho_1}{\lambda_1} \cdot \epsilon^2 \qquad \ldots.(6)$$

B. *The Liquid is Above its Melting Point. Transport of Heat Through the Liquid by Conduction Only*

Application of the Fourier equation to both crystal layer and liquid layer using the assumptions and the following boundary conditions,

(a) $x = 0$, $T_1 = T_{10}$; (b) $x = \epsilon$, $T_1 = T_2 = T_s$; (c) $x = \infty$, $T_2 = T_{20}$; (d) $\lambda_1 \left(\frac{\delta T_1}{\delta x}\right)_{x=\epsilon} = \lambda_2 \left(\frac{\delta T_2}{\delta x}\right)_{x=\epsilon} + L\rho_1 \frac{\delta \epsilon}{\delta \theta}$,

gives:

for the crystal layer:

$$\frac{T_s - T_1}{T_s - T_{10}} = 1 - \frac{B_1}{T_s - T_{10}} \operatorname{erf} \frac{x}{2\sqrt{a_1\theta}} \qquad \ldots.(7)$$

for the liquid layer:

$$\frac{T_2 - T_s}{T_{20} - T_s} = 1 + \frac{B_2}{T_{20} - T_s} \operatorname{erfc} \frac{x}{2\sqrt{a_2\theta}} \qquad \ldots.(8)$$

At the interface $T_1 = T_2 = T_s$, $x = \epsilon$ (see above). Therefore:

$$B_1 \operatorname{erf} \frac{\epsilon}{2\sqrt{a_1\theta}} = T_s - T_{10} \qquad \ldots.(9)$$

and:

$$-B_2 \operatorname{erfc} \frac{\epsilon}{2\sqrt{a_2\theta}} = T_{20} - T_s \qquad \ldots.(10)$$

These equations must be valid for all values of θ. Therefore:

$$\theta = \frac{1}{4K} \epsilon^2 \qquad \ldots.(11)$$

The value of the proportionality constant K can be obtained by differentiation of Equations (7), (8) and (11) and eliminating B_1 and B_2, from which:

$$\frac{\lambda_1 (T_s - T_{10})\, e^{-K/a_1}}{\sqrt{\pi a_1} \cdot \operatorname{erf} \sqrt{K/a_1}} = \frac{\lambda_2 (T_{20} - T_s)\, e^{-K/a_2}}{\sqrt{\pi a_2} \cdot \operatorname{erfc} \sqrt{K/a_2}} + L\rho_1 \sqrt{K} \qquad \ldots.(12)$$

C. *The Liquid is Above its Melting Point. Transport of Heat Through the Liquid by Free Convection and Conduction*

The Fourier equation can again be applied to the crystal layer. The transport of heat through the liquid can be represented by an equation of the form $\varphi'' = h(T_{20} - T_s)$, because the experiments have been carried out in such a way that up to a certain distance f from the crystallisation plate the liquid has been kept at the constant temperature T_{20}. The following boundary conditions therefore apply:

(a) $x = 0$, $T_1 = T_{10}$; (b) $x = \epsilon$, $T_1 = T_2 = T_s$; (c) $x > f$, $T_2 = T_{20}$; (d) $\lambda_1 \left(\frac{\delta T_1}{\delta x}\right)_{x=\epsilon} = \varphi'' + L\rho_1 \frac{\delta \epsilon}{\delta \theta}$.

Therefore, for the crystal layer:

$$\frac{T_s - T_1}{T_s - T_{10}} = 1 - \frac{\operatorname{erf} \frac{x}{2\sqrt{a_1\theta}}}{\operatorname{erf} \frac{\epsilon}{2\sqrt{a_1\theta}}} \qquad \ldots.(13)$$

and from the condition d:

$$\frac{\lambda_1 (T_s - T_{10}) e^{-\frac{\epsilon^2}{4a_1\theta}}}{\sqrt{\pi a_1\theta} \cdot \operatorname{erf} \frac{\epsilon}{2\sqrt{a_1\theta}}} = h(T_{20} - T_s) + L\rho_1 \frac{\delta \epsilon}{\delta \theta} \qquad \ldots.(14)$$

If the heat flux through the crystal layer is infinitely large compared with the rate of increase of the amount of sensible heat of the crystal layer, and if the $T_1 - x$ line is a straight line, then Equation (14) reduces to:

$$\lambda_1 \frac{T_s - T_{10}}{\epsilon} = h(T_{20} - T_s) + L\rho_1 \frac{\delta \epsilon}{\delta \theta} \qquad \ldots.(15)$$

If the partial coefficient of heat transfer h is constant, Equation (15) gives by integration for constant values of $(T_{20} - T_s)$:

$$\theta = \frac{L\rho_1\lambda_1 (T_s - T_{10})}{h^2 (T_{20} - T_s)^2} \ln \frac{\lambda_1 (T_s - T_{10})}{\lambda_1 (T_s - T_{10}) - h(T_{20} - T_s)\epsilon} - \frac{L\rho_1}{h(T_{20} - T_s)} \epsilon \qquad \ldots.(16)$$

Experimental

Apparatus

To realise as closely as possible the condition of unidirectional heat flow, the following apparatus was used. A

circular copper plate of 8 cm diameter and 0.2 cm thickness was used for the crystallisation plate. By means of an epikote adhesive, this plate was mounted in an ebonite ring of 0.8 cm thickness, which formed the bottom part of the cooling section. This section consisted further of a glass cylinder of 8 cm diameter and length of 30 cm, mounted by a flange on the ebonite ring, just over the crystallisation plate. A teflon ring between flange and ring prevented leakage. The glass cylinder was closed by means of a plate, provided with three openings, one for a thermometer, one for the cooling liquid filling funnel, and the third opening, the outlet for the vapours of the boiling cooling liquid, was connected to two condenser tubes placed in liquid air and to a manostat. The cooling section was isolated by means of a layer of glasswool of 1 cm thickness. A protecting mantle was mounted on the ebonite plate at some distance from the cooling section.

The crystallisation plate was cooled by boiling one of the following: ether, freon 11, Arcton 4 or Arcton 6, depending on the desired temperature, at a constant pressure, controlled by the manostat. The vapour thus formed was condensed in the condenser tubes. Temperatures were measured by means of thermocouples of 0.01 cm gauge copper-constantan. These were located at the upper and underside of the crystallisation plate and at 12 points in the crystal- and liquid-layer beneath the plate at different distances from it. This group of thermocouples was mounted in the centre of the plate, in a tube (diameter 1 cm, length 2 cm) of low heat conductivity material (Akulon). The thermocouple tips protruded 0.15 cm outside the tube, and were placed in a spiral; the wires passed the Akulon tube to the measuring instrument. The distances between the thermocouple joints and the plate, important for the evaluation of the results, were measured with a kathetometer, the centre line of the joints being taken as reference. The joints were silver soldered to ensure ruggedness. The thermocouple tube was attached by means of an epikote adhesive in a hole in the crystallisation plate, its position being made secure by means of a bent strip screwed to the ebonite ring.

The thermocouples were read by means of a three-decade compensator (Bleeker, type 2165) in combination with a sensible galvanometer (Kipp, A 70) as a zero-point indicator. This set-up enabled one to read temperature-differences of $\sim$0.07°C.

The crystallisation plate was brought into contact with the liquid to be investigated by immersing the underside of the cooling section up to a depth of $\sim$2 cm into the liquid, which was contained in a cylindrical vessel. This vessel, provided with a stirrer, had a capacity of 15 litres and contained $\sim$12 litres of liquid. The liquid was brought to the desired temperature, with stirring, by pumping a thermostatically controlled brine through a closely wound copper spiral immersed in the liquid. The vessel was insulated thermally by means of a layer of cotton-wool surrounded by a glass mantle. The upperside of the apparatus was insulated with wood.

A diagrammatic drawing of the whole crystallisation apparatus is given in Fig. 1, together with some important details.

Most of the work was carried out with water and, in addition, some experiments were performed with benzene. To prevent the formation of porous crystal layers the liquid had to be degassed as thoroughly as possible. With water this could be done by boiling the liquid for a long time and cooling in the absence of air. For benzene the same method was not satisfactory, due to the great solubility of air in benzene. The best results for benzene were obtained by a process of repeated freezing and melting under suction. The benzene was, however, never quite air-free.

Results

The results will be grouped under the same paragraphs as given in the theoretical part.

TABLE I

Exp. No.	20	21	22	23	24	25
$T_s - T_{10}$	29.5	29.4	20.4	20.4	12.6	12.2
$\lambda_1 \times 10^3$	0.66	0.53	0.79	0.81	0.82	0.77

TABLE II

No.	Duration in sec.	T_{20} °C	$T_s - T_{10}$ °C	θ_e sec	$\frac{1}{4K}$	K $\times 10^3$	$K_{calc.}$ $\times 10^3$	b
29	2500	4	6.9	60	1190	0.21	0.22	−5
30	2400	4	6.6	38	1282	0.19	0.21	−9
5	2100	4	12.9	−126	575	0.44	0.41	7
6	2100	4	12.8	−105	552	0.45	0.44	2
39	1800	4	23.2	69	313	0.80	0.78	3
42	1250	4	23.6	32	303	0.83	0.76	9
46	1250	4	30.7	31	208	1.20	0.98	22
51	1400	4	31.6	20	212	1.20	1.03	16
31	2500	2	7.1	42	1053	0.24	0.24	0
32	2500	2	7.4	51	1020	0.25	0.25	0
8	2300	2	13.2	−111	565	0.44	0.44	0
9	2300	2	23.3	−27	546	0.46	0.45	2
40	1350	2	22.9	55	297	0.84	0.78	8
41	1350	2	23.6	52	285	0.88	0.80	10
47	1200	2	30.8	34	209	1.20	1.06	13

TABLE III

	No.	$T_s - T_{10}$ °C	θ sec.	ϵ cm	r	ϵ_∞ cm	h $\times 10^3$	h^1 $\times 10^5$	δ cm	δ_e cm	h_f $\times 10^3$	δ_f cm
Series I	26	7	1800	0 57	0.98	0.58	6.4	6.3	3 43	0.08	10.7	3.35
	16	7	1200	0.52	0.95	0.56	6.6	5.5	3.48	0.08	11.0	3.40
	12	13	1920	1.19	0.81	1.47	4.7	5.1	2.81	0.11	7.8	2.70
	13	13	2160	1.14	0.88	1.30	5.3	5.7	2.86	0.10	8.8	2.76
	34	23	1440	1.68	0.58	2.90	4.2	4.6	2.32	0.12	7.0	2.20
	33	23	1440	1.60	0.65	2.46	4.9	5.3	2.40	0.11	8.2	2.29
	43	31	1320	2.06	0.43	4.79	3.4	3.5	1.94	0.15	5.7	1.79
Series II	21	7	2640	0.91	0.88	1.03	4.2	5.8	3.09	0.15	8.0	2.94
	18	7	1680	0.92	0.72	1.28	3.4	4.8	3.08	0.18	6.4	2.90
	15	13	2280	1.63	0.55	2.96	2.7	4.1	2.37	0.23	5.1	2.14
	14	13	2280	1.61	0.57	2.83	2.9	4.1	2.39	0.21	5.5	2.18
	35	23	1320	1.82	0.38	4.79	3.0	4.5	2.18	0.20	5.7	1.98
	36	23	1200	1.73	0.38	4.55	3.2	5.0	2.27	0.19	5.9	2.08
	49	31	1320	2.25	0.23	9.78	2.0	2.3	1.75	0.30	3.8	1.45
	44	31	1320	2.24	0.24	9.33	2.1	2.8	1.76	0.29	4.0	1.47
Series III	27	7	2640	1.23	0.61	2.01	2.6	3.1	2.77	0.29	6.1	2.48
	28	7	2280	1.18	0.57	2.07	2.6	2.4	2.82	0.29	6.1	2.53
	10	13	2640	1.87	0.44	4.25	2.3	3.2	2.13	0.32	5.4	1.81
	11	13	2520	1.87	0.38	4.92	2.0	3.5	2.13	0.37	4.7	1.76
	38	23	960	1.74	0.12	14.5	1.2	1.3	2.26	0.62	2.8	1.64
	37	23	1320	1.96	0.20	9.80	0.8	2.6	2.04	0.93	1.9	1.11
	50	31	1560	2.58	0.12	21.5	1.1	1.2	1.42	0.67	2.6	0.75
	45	31	1200	2.31	0.08	28.9	0.8	1.1	1.69	0.93	1.9	0.72

Liquid at its Melting Point (work carried out with Ph. Beeliën and C.Th. Douwes)

Mode of Operation

The liquid was brought to its melting point by cooling with stirring. A thick, closed, crystal layer around the cooling spiral is formed during this process. This is advantageous, because this layer serves as a good extra insulant. During the conditioning of the liquid the cooling section was evacuated to the desired pressure, the funnel filled and the condenser tubes placed in liquid air. The cooling section was then immersed into the liquid, stirring stopped and the cooling liquid sucked in. This is zero time.

At intervals of 10 sec. after this moment each thermocouple was read until the end of the experiment. The amount of cooling liquid could be chosen to give each experiment a duration of 40-70 min.; the crystal layer formed was of 1-2 cm. It had a flat surface, the edges only were rounded.

The preparations for the next experiment included the removal of the ice layer; this was done by melting the layer with the cooling section still within the apparatus.

A heat balance over the whole duration of the experiment was made from time to time by comparing the amount of ice formed (obtained by taking out the cooling section and melting the ice carefully and weighing the amount of water) with the amount of cooling liquid evaporated. With the aid of the known values of the heats of evaporation and of crystallisation it could be concluded that differences were smaller than ~5%. Moreover, no temperature gradient in a horizontal plane was found. Therefore, the apparatus was considered to be fairly substantially adiabatic. The temperature drop over the crystallisation plate was negligible as was to be expected.

Evaluation of the Experiments

The temperature-time relation was measured for each thermocouple. These data can be transformed by means of the known distances from the crystallisation plate to the couples, to $T_1 - x$ relations at known times. According to theory, these lines ought not to be straight. However, with the exception of a thin layer near the crystallisation plate, the $T_1 - x$ relations found are not to be distinguished from straight lines. This facilitates the determination of ϵ for the corresponding time which can then easily be found by linear extrapolation to $T_1 = T_s$. It has been found for theoretical cases comparable to the actual experiments, that by linear extrapolation the error in $4\,a_1\beta^2$ is not larger than 2%. The deviation of the temperature lines near the plate is not caused by the factor mentioned, but depends in all probability on irregularities in the building up of the crystal layer.

In order to apply Equation (6) to the experiments, it is necessary that T_{10}, the plate temperature, is constant throughout an experiment. As can be deduced, this will never be the case in the actual experiments if the pressure in the cooling section is kept constant. The partial coefficient of heat transfer in the boiling liquid is either not infinite as compared with λ_1, or not constant with the time. This coefficient has been found to decrease with the heat flux and therefore with time. In principle a constant plate temperature can be approached, based on the behaviour described, if the boiling point of the cooling liquid is increased with time; in this case, therefore, the pressure in the cooling section must increase.

The technique was so developed that by slowly increasing the pressure in the cooling section, after a period of ~400 sec., the plate temperature did not deviate more than ±0.5°C from the mean temperature. An example of the change of the plate temperature with the time under the conditions described is given in Fig. 2.

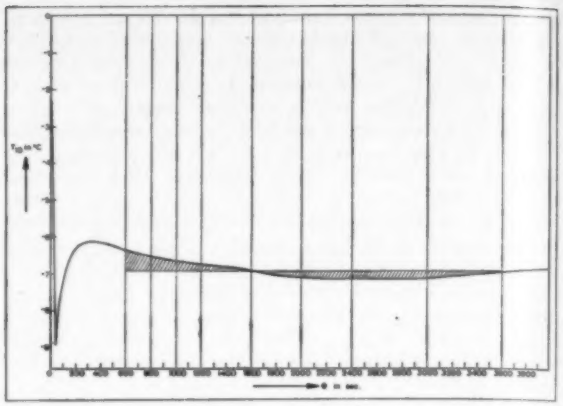

Fig. 2. Graph showing the change of plate-temperature with time. (Exp. No. 14).

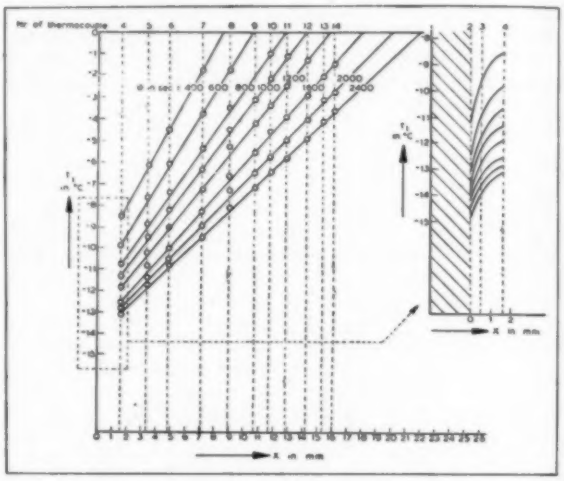

Fig. 3. The relation between the temperature T_1 *and the distance* x *from the crystallisation plate at different times. (Exp. No. 12.)*

The Results for Water

Experiments have been carried out with $T_s - T_{10}$ varying from 5.57 to 13.42°C. The results are given graphically; in Fig. 3 some typical $T_1 - x$ relations are given. The zone previously mentioned can be clearly seen; the lines for different times do not intersect in one point on the crystallisation plate.

For the behaviour near the crystallisation plate a definite explanation has yet to be found; different orientation of the crystals, the presence of small amounts of air or irregular pattern of crystallisation centres may be the cause.

From the results obtained the values of ϵ can be found by extrapolation and the relation between θ and ϵ^2 found. These have been presented in Fig. 4 for different values of $T_s - T_{10}$. For each experiment the points can be connected by a straight line, which almost passes the origin. The deviations are larger for larger values of $T_s - T_{10}$. According to Equation (6), the slope of the $\theta - \epsilon^2$ line should be $\frac{L}{2(T_s - T_{10})} \frac{\rho_1}{\lambda_1}$ and the line should pass the origin. Although the last condition is not fulfilled, it may be noted that the differences are small and might well be caused by the plate effect mentioned above.

In Fig. 5 the reciprocal values of the slopes of the $\theta - \epsilon^2$ lines have been plotted against the corresponding values of

$T_s - T_{10}$. The best correlation is again a straight line, which must be the case if the assumption that ρ and λ are constant is valid. The slope of the line is $\frac{2\lambda_1}{L\rho_1}$ and it should pass through the origin. This last condition is very nearly fulfilled, as will be shown later. The value of $\frac{2\lambda_1}{L\rho_1}$ thus found is 150 10^{-6}.

The ice crystals formed were observed to orientate themselves with their long axes in the direction of heat flow. Using the corresponding value of λ_1, the theoretical value of $\frac{2\lambda_1}{L\rho_1}$ should be 145 10^{-6}. The agreement is fairly good.

The Results for Benzene

Some of the relations found between θ and ϵ^2 are presented in Fig. 6 to show that the deviations from a straight line are larger than those for water and, moreover, that the lines do not pass through the origin. A systematic error seems therefore to be present. It had been observed during the experiments that thermocouples were, while still in the liquid zone, already covered with solid benzene. Moreover, the crystal front near the thermocouple tube showed markedly rounded edges. This shows that one of the causes of deviation is a relatively large heat flow through the thermocouple tube. This is easily explained by noting that the thermal conductivity of solid benzene is of the same order as that of Akulon (0.6 10^{-3}), as will be shown below, whilst the thermal conductivity of ice is 5.3 10^{-3}. The error introduced in this way could not be remedied easily because no suitable material with a much smaller thermal conductivity value has been found.

In the second place the rather large amount of air present in the solid benzene layer could magnify the effect.

As for water from the slopes of θ-ϵ^2 lines the value of $\frac{2\lambda_1}{L\rho_1}$ can be found. This has not been done by a graphical method as in the case of water to give a mean value, because experiments with large $T_s - T_{10}$ values have given rather large deviations and a straight line could not very well be drawn through the points. Instead, values have been calculated for each experiment by simple division of the reciprocal value of the slope through $T_s - T_{10}$. From these values the thermal conductivity λ_1 has been calculated. These are presented in Table I.

Observing that Experiments 20 and 21 for the largest temperature difference $T_s - T_{10}$ show rather great deviations in one direction, it seems safe to conclude that the thermal conductivity of solid benzene as orientated in the direction of heat flow is 0.80×10^{-3}, which is the mean of the last four experiments. The value of the heat conductivity of solid benzene as formed has not been described in the literature and could therefore not be compared.

Liquid above its Melting Point. Heat Transport Through the Liquid by Conduction Only (work carried out with P. A. Staring)

These experiments have been carried out with water only.

Mode of Operation

In order to approach the condition that heat is transported through the liquid by conduction only, mixing effects caused by density differences must be prevented. This can be realised by using water between 0 and 4°C, because of the density maximum at this last temperature.

Evaluation

The experiments have been carried out as described under A with the following alterations. Since no crystal layer is formed around the cooling-spiral, some insulating capacity is lost. During an experiment the temperature of

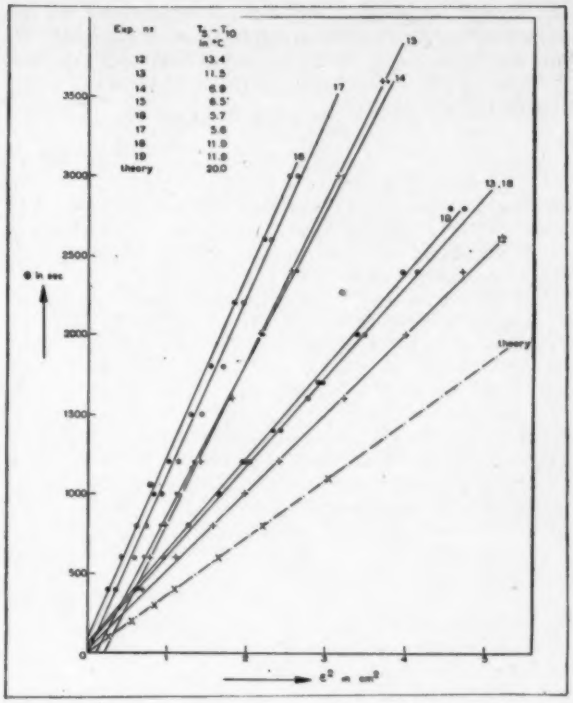

Fig. 4. The relation between ϵ^2 and the time θ for water at its melting point.

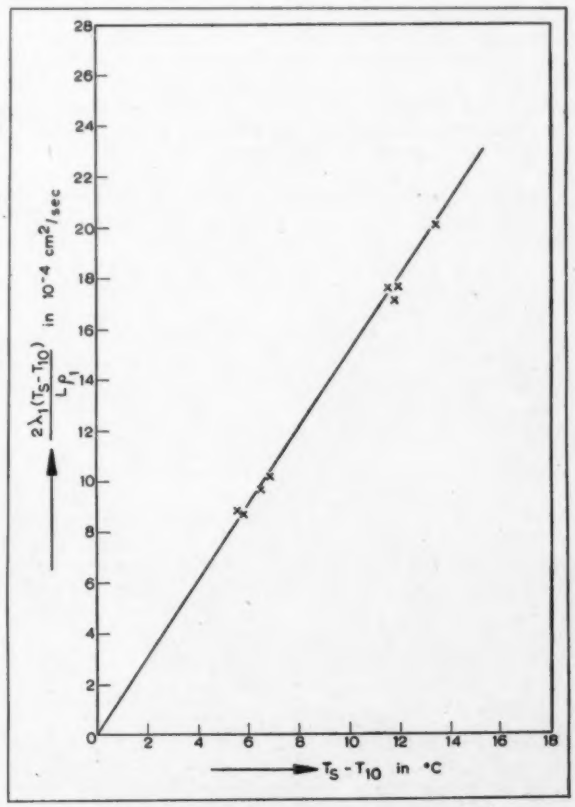

Fig. 5. The reciprocal value of the slope of the $\theta - \epsilon^2$ lines $\frac{2\lambda_1(T_s-T_{10})}{L\rho_1}$ versus the temperature difference $T_s - T_{10}$.

the liquid rises slowly. This increase is compensated by brine-cooling, as soon as the temperature in the centre of the apparatus, 4 cm from the crystallisation plate, has increased 0.1°C. This manner of operation causes an error which is discussed later.

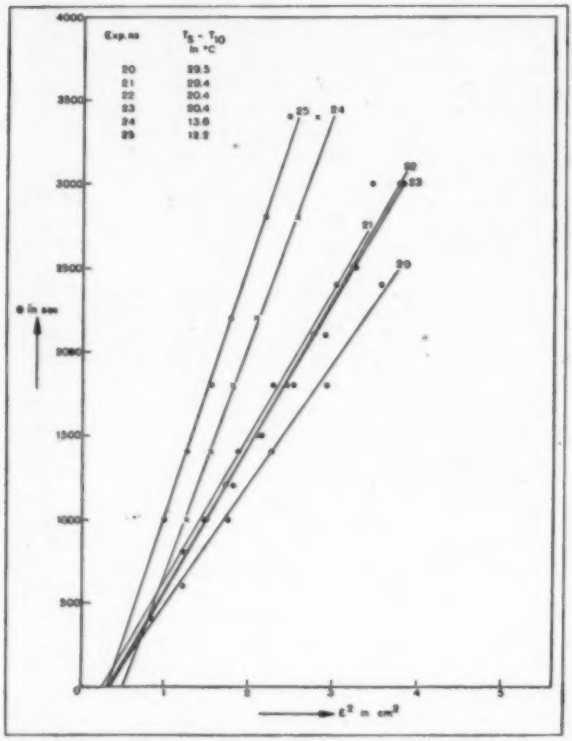

Fig. 6. The relation between ϵ^2 and the time θ for benzene at its melting point.

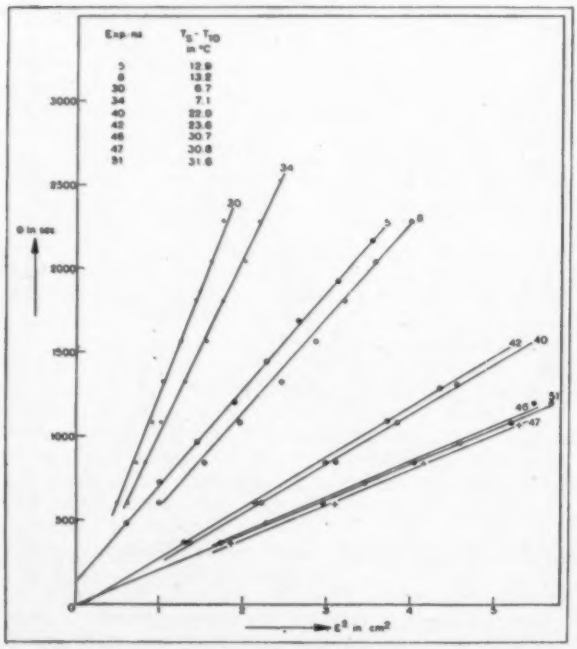

Fig. 7. The relation between ϵ^2 and the time θ for water above its melting point.

The second alteration is that the beginning of the crystallisation does not coincide with the beginning of the experiment. Undercooling has been observed at the crystallisation plate. The temperature of the plate at the beginning falls rapidly to −0.5°C, then suddenly rises to +0.5°C, then decreases again. The time at which the plate again reaches the temperature 0°C has been taken as zero time.

Results

The experiments were evaluated as under A. For each series a set of θ-ϵ^2 values was found, some of which are given in Fig. 7. The points are again best connected by a straight line, in accordance with Equation (11). However, the lines do not pass through the origin. The deviations are larger than analogous deviations described under A. They might well be attributed to the effect mentioned and the choice of zero time. The deviation will be included as a time correction θ_c and Equation (11) written as:

$$\theta + \theta_c = \frac{1}{4K}\epsilon^2$$

The values of θ_c, $\frac{1}{4K}$, K, K_{cal} (the K value as calculated from Equation (12)), $b = (1/K_{cal})\ (K\text{-}K_{cal}) \times 100\%$ as well as some experimental data are collected in Table 2.

The K values found experimentally are, for most experiments, greater than those demanded by theory, the relative difference increasing with increasing $T_s - T_{10}$ and with T_{20}. If the temperature T_{20} at an infinite distance is constant, as assumed in the theory, at a finite distance the temperature will decrease. Keeping the temperature at a finite distance constant, which was the case here, signifies that T_{20} was increased slowly during the experiment. This increase can be calculated and for the maximum period of time used (2500 sec.) is 1.2°C. From Equation (12) it is seen that K is, for example, a function of T_{20}. It has been calculated that an increase of T_{20} of 1°C causes a decrease of K of ∼2%, which is almost independent of $T_s - T_{10}$. Therefore, the θ-ϵ^2 lines as determined should be slightly curved.

By drawing the straight lines, a mean value for K was obtained, which in the most unfavourable case did not differ by more than ∼1% from the calculated value. It can therefore be concluded that the error introduced is small and does not explain the values of b. Moreover, it is clear that the error introduced makes it difficult to distinguish the curved lines from straight lines.

The increase of b with $T_s - T_{10}$ seems to point to an undercooling of the liquid at the interface. However, it can be pointed out that undercooling signifies a decrease in $T_s - T_{10}$ and the same increase in $T_{20} - T_s$; moreover, the value of ϵ should be smaller by the same relative effect by virtue of the extrapolation technique. Comparing these effects with the change in K for a decrease in $T_s - T_{10}$ and an increase in $T_{20} - T_s$ as can be found from Equation (12), we conclude that undercooling alone—if any—cannot be the cause of the differences found.

Liquid above its Melting Point. Heat Transfer Through the Liquid by Free Convection and Conduction (with P. A. Staring)

Temperatures higher than 4°C have been chosen. The mode of operation and the evaluation have been the same as described under B, keeping the temperature at 4 cm from the plate at a constant value. Three series of experiments with water have been carried out: series I: $T_{20} = 10$°C; series II: $T_{20} = 8.5$°C; series III: $T_{20} = 7.0$°C. From the experimental technique it can be concluded that at infinite time a stationary condition will be reached in which the net heat leaking into the crystallisation section will be equal to the heat transported by the evaporating liquid. In this case the thickness of the ice layer and the coefficient of

TABLE IV

From		Series I	Series II	Series III
h_f and δ_f	d	0.7	0.7	0.7
	c'	3.1×10^{-3}	2.6×10^{-3}	2.5×10^{-3}
	c	1.0×10^{-3}	1.0×10^{-3}	0.95×10^{-3}
h and δ	d	0.7	0.8	0.9
	c'	1.6×10^{-3}	1.0×10^{-3}	0.5×10^{-3}
	c	3.7×10^{-4}	1.6×10^{-4}	0.16×10^{-4}
h' and δ	d	0.7	0.8	0.9
	c'	1.9×10^{-3}	1.3×10^{-3}	0.5×10^{-3}
	c	4.4×10^{-4}	2.1×10^{-4}	0.16×10^{-4}

free convection should reach a constant value. It has been found from the ϵ-θ lines, using Equation (15) for the calculation of h, that h increases with time, reaching after $\sim$1200 sec. a value which is reasonably constant. Now the determination of h in this way is rather inaccurate, mainly because the $\frac{d\epsilon}{d\theta}$ value is inaccurate and too large, even if calculated from the last two measured points. An approximation technique has therefore been used, which has no direct bearing on the actual situation, by assuming that T_{20} is kept constant during the whole experiment on an infinite distance (not as done at 4 cm) and that h remains constant over the whole region. In such a case Equation (16) should be valid, and has been used over the region in which h is almost constant. From Equation (16) it follows that for infinite time the numerator under the log sign should be zero. If the corresponding (for the actual case hypothetical) value of the thickness of the ice layer at infinite time is denoted by ϵ_∞, then:

$$\lambda_1(T_s - T_{10}) = h(T_{20} - T_s)\ \epsilon_\infty \qquad \ldots.(17)$$

By substituting in Equation (16) the term $h\ (T_{20} - T_s)$, with the aid of Equation (17) the result is:

$$\theta \frac{\lambda_1 (T_s - T_{10})}{L\rho_1} = -\epsilon_\infty^2 \left[2.3 \log \left(1 - \frac{\epsilon}{\epsilon_\infty}\right) + \frac{\epsilon}{\epsilon_\infty}\right] \qquad \ldots.(18)$$

This equation can be written in the form:

$$\theta p = \epsilon^2 q \qquad \ldots.(19)$$

in which $p = \frac{\lambda_1 (T_s - T_{10})}{L\rho_1}$ and $q = -\frac{1}{r^2}[2.3 \log (1 - r) + r]$, where r stands for $\frac{\epsilon}{\epsilon_\infty}$.

Using each *last* point measured, the value of log q can be calculated by means of Equation (19), the corresponding value of r can be read from a graph representing log q as a function of r, which can be readily found. From the value of r, ϵ_∞ and, by Equation (17), the value of h have been found. The values of r, ϵ_∞ and the corresponding h have been collected in Table III. The values of the heat-transfer coefficient as found with the aid of Equation (15) have also been included in Table III as h'.

Heat transfer through the liquid layer takes place partly by free convection. However, at 4°C a density maximum is present. It seems likely, therefore, that the liquid layer has to be split up into two zones: a zone near the ice surface from 0-4°C through which, in view of the results previously described, heat is transported by conduction only, and a zone from 4-T_{20}°C in which heat is transported solely by free convection. If the thickness of the first zone is δ_c, that of the second zone δ_f and if the partial coefficient of heat transfer by free convection is h_f, then the following relations hold:

$$\left.\begin{aligned} h(T_{20} - T_s) = \frac{\lambda_2}{\delta_c}(4 - T_s) = h_f(T_{20} - 4) \\ \delta_c + \delta_f = \delta = 4 - \epsilon \end{aligned}\right\} \qquad \ldots.(20)$$

From the experimental values the unknowns h_f, δ, δ_c and δ_f can be calculated. These values are included in Table III.

From the literature on the partial coefficient of heat transfer for free convection for horizontal plates it seems safe to assume that the following relation holds:

$$\mathrm{Nu} = c(\mathrm{Gr.Pr.})^d \qquad \ldots.(21)$$

or:

$$h_f = c\frac{\lambda_2}{\delta_f}\left(\frac{g\delta_f^3\ \alpha\ (T_{20} - T_s)\ \rho_2^2\ (c_p)_2}{\eta_2\lambda_2}\right)^d \qquad \ldots.(22)$$

also

$$h_f = c'\ (\delta_f)^{3d-1} \qquad \ldots.(23)$$

By plotting log h_f versus log δ_f, for constant values of $T_{20} - T_s$, the value of d can be found via the slope of the line. Although especially for series III the points are rather scattered, nevertheless the conclusion must be that the linear relationship demanded exists. The values found for d, c' and also c have been collected in Table IV.

For comparison the same data have been established from h and δ, as well as from h' and δ. In these two cases the log h-log δ points showed much more scatter than in the first case, thereby impairing the accuracy.

It seems safe to conclude from Table IV, observing that d and c should be constant for the three series, that the picture of the two liquid layers is rather well confirmed. It may be noted that in the literature for the Grashof numbers values for d of $\sim\frac{1}{4}$ have been given. The explanation of the difference might lie in the choice of the length parameter.

Discussion

The experimental set-up and the mode of chosen operation have made it possible to define the physical process clearly. Therefore, the relatively simple mathematical expressions for the crystallisation of a simple substance by unidirectional cooling could be illustrated, mainly for the crystallisation of water.

The linear relationship between time and the square of the thickness of the crystal layer, if the liquid is at its melting point, is established quite well. The proportionality constant for water is in good agreement with literature data. For benzene, from this proportionality constant, the unknown thermal conductivity of solid benzene could be found.

Again, the experiments with the liquid above its melting point, with heat transport through the liquid by conduction only, obeyed the same linear relationship as in the former case, as required by theory. The proportionality constants found are in good agreement with theory, with the exception of the experiments at high cooling rates. In these cases the proportionality constant is higher than predicted. This is not caused by undercooling of the liquid only.

For the experiments with water, in which heat through the liquid is at least partly transported by free convection, the conclusion has been reached that the liquid layer consists of two zones: the first zone near the crystallisation front, up to a temperature of 4°C, in which heat is transported by conduction only; the second zone, up to the front where the liquid is kept at a constant temperature, through which heat is transported by free convection. The relation between the Nusselt number of free convection and the product of Grashof and Prandtl number shows much higher values than described in the literature. In all the experiments no undercooling of the liquid at the interface crystal-liquid has been detected.

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FILTRATION OF THE GASEOUS EFFLUENT OF AN AIR-COOLED REACTOR

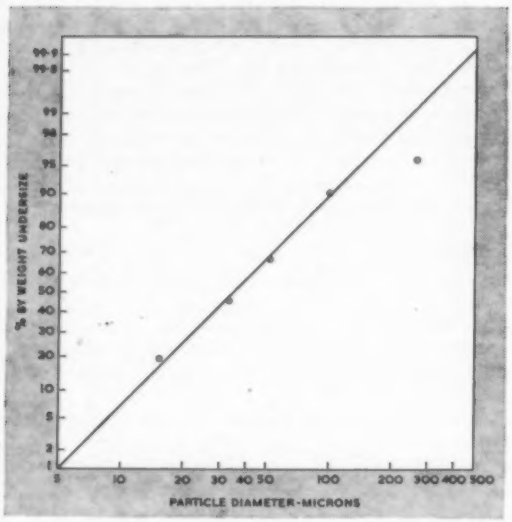

Fig. 1. Size distribution of uranium oxide dust.

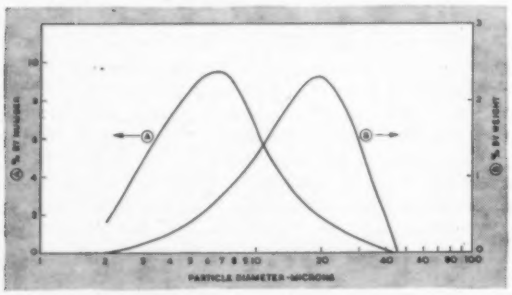

Fig. 2. Size distribution of portion of cyclone sample of Dallast dust.

TABLE I—Comparison between Effluents of a Windscale Pile and Power Station (Power Station data from England *et al.*, *J. Inst. Fuel*, 30, 200, 511 (September 1957))

	Power Station	*Pile*
Gas flow at stack exit (ft^3 $sec.^{-1}$)	3633	—
Gas temperature (°C)	118	—
Gas velocity at stack exit (ft $sec.^{-1}$)	23.6	34
Gas flow at atmospheric temperature (ft^3 $sec.^{-1}$)	2632	30,000
Dust content at atmospheric temperature (gm ft^{-3})	2.3×10^{-2}	2.3×10^{-6}
Rate of dust emission (gm $sec.^{-1}$)	61	69×10^{-3}
Dust penetration	16%	<10%
Nominal power output	27 MW (electrical)	—

Over a period of six years, work at the Windscale pile resulted in a big improvement in the performance of filters for the stack effluent. Development posed problems not encountered in normal industrial practice

by I. A. MOSSOP, B.Sc. Tech. (Manchester), A.M.I.E.E.*

THE removal of solid particulate matter from a gas stream is a fairly common industrial problem which can be tackled satisfactorily using conventional equipment such as cyclones, electrostatic precipitators, scrubbers and material filters, but the conditions associated with the filtration of the stack effluent of a once-through air-cooled reactor make the solution of this particular problem much more difficult (Table I). This article outlines these restrictions and conditions and describes the type of filter found most suitable for this application.

Nature of the Problem

The factors which contribute to the difficulty of the problem are summarised below without any attempt having been made to list them in any particular order:

(1) The effluent is a high-velocity, large volume gas stream. There exists little industrial experience of the filtration of this form of effluent. Typical conditions are 1 ton of gas per sec. at a stack velocity approaching 2000 ft a min.

(2) The gas reaches the filters at a relatively high temperature which restricts the choice of filter material.

(3) Because of structural and operational considerations, the maximum permissible pressure drop across the filters is limited to a few mm Hg.

(4) Without major modification to the existing installation the maximum size of the filters is severely restricted. The present filter frames, for example, have a depth of only 2 in.

(5) The quantity, specific activity and size composition of the dust reaching the filters varies over wide limits.

(6) Because of its activity and biological significance, the quantity of the particulate matter which can be allowed to penetrate the filters is small. For the same reasons, the dust stopped by the filters presents a handling and disposal problem.

(7) To reduce handling to a minimum the filter should be sufficiently cheap so that to discard it after use is not economically crippling.

The Dust to be Filtered

The particulate matter in the gaseous effluent of an air-cooled reactor consists of atmospheric dust which has eluded the inlet filters, dust generated within the reactor such as concrete, graphite or metal dust, and particulate matter

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containing fission products emanating from exposed uranium. All materials are made active to some extent in passing through a reactor, but from all the particulate matter within the effluent only that containing fission products is likely to constitute a hazard. It is thus essential to know the contribution from and the size distribution of the component containing the fission products, since they determine the performance required of the filter. A measurement has been made of these quantities utilising the dust collected by a cyclone sampling through a 2-in. pipe just below the filters. The larger size particles were separated using graded sieves and the remainder were sized in a multi-stage liquid elutriator. Methanol was the liquid chosen for the elutriator which was calibrated using graded copper dust as a suitable substitute dust with a density near the average density of the particles containing uranium. The uranium content of each size range was then estimated chemically and the number of particles calculated for each group. The size distribution of a sample for a 25-day period of normal running is shown in Fig. 1. This general size distribution has been confirmed by Megaw at A.E.R.E., Harwell, from measurements of the oxidation of uranium in a heated stream of air. By a comparison with the total weight of the cyclone sample it was found that the uranium component represented only about 0.1% by weight. In addition, a very rough estimation of the size distribution of the ballast dust was made by sizing a portion of a cyclone sample. This portion, containing approximately 1000 particles, was sized using a microscope. Presumably because of its smallness, this sized portion was not found to contain particles larger than about 50 microns, although clearly some must have been present in the bulk sample.

Since the useful life of the oiled impaction type of filter was determined by loss of oil and blow-off of particles rather than increase in pressure drop, the exact nature of the ballast was not of prime importance. As a consequence, a more accurate but time-consuming estimation of its size distribution was never made. The results of this simple measurement are shown in Fig. 2. In the conversion from number to weight, spherical particles with a density of 2 gm cm^{-3} has been assumed.

Principles of Sieve Impaction Filters

From the previous sections it can be concluded that the problem is one of filtering a highly active dust in the presence of approximately 1000 times its weight of biologically harmless ballast. Although this ballast does not contribute much to the hazard, it does, however, materially add to the difficulties of the problem in prematurely loading the filter.

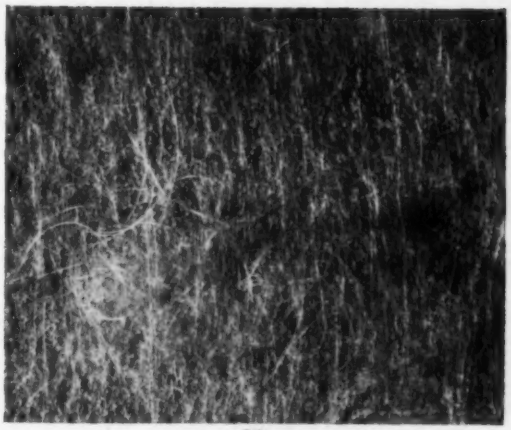
Filters operating on sieve and impaction principles or a combination of the two have been used at Windscale. The principle of operation of the sieve filter is well known; particles larger than the aperture size are unable to pass through the filter and are thus stopped. The impaction filter is probably less well known (although the principle is used rather crudely in "viscous" filters and the Calder-Fox scrubber) and can only be used where the gas velocity through the filter is sufficiently high for the solid particulate matter to be unable to follow the streamline flow and be "impacted out" when the stream is made to negotiate a series of obstructions. In this application such obstructions take the form of a random space arrangement of glass fibres.

To prevent blow-off and migration of dust through an impaction filter, it is necessary to maintain an adherent layer, such as a film of oil, on the surface of the fibres.

Sieve types of filter gradually clog as the apertures become filled with trapped particles. This results in an increase in pressure drop (in general accompanied by an increase in efficiency) and necessitates the replacement of the filter. Impaction filters, on the other hand, are not affected in this way, since the particles being stopped are usually small

Fig. 3. "D" type fibre filter.

(a)



(b)

Fig. 4. Battery mat or starch bonded staple tissue.
(a) Plan view.
(b) Side elevation showing nap on surface of battery mat.

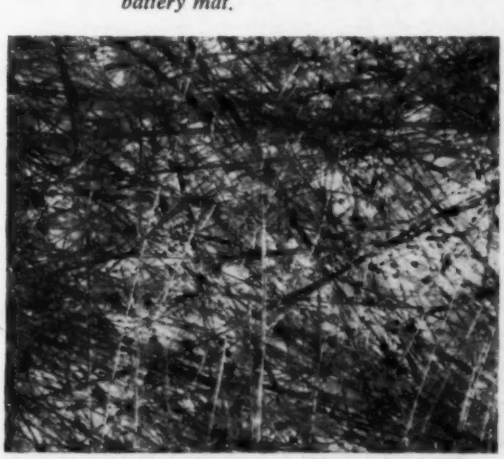


Fig. 5. "Fibreglass" coarse fibred material.

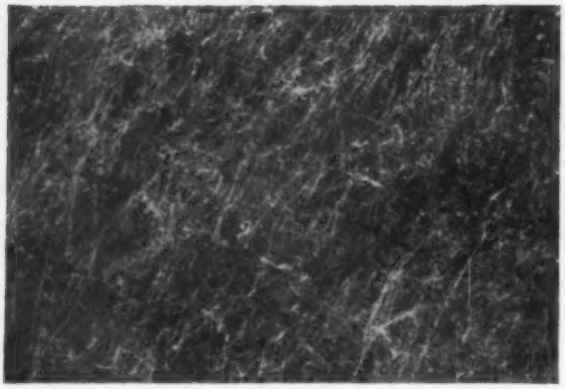


Fig. 6. R.50 filter material.

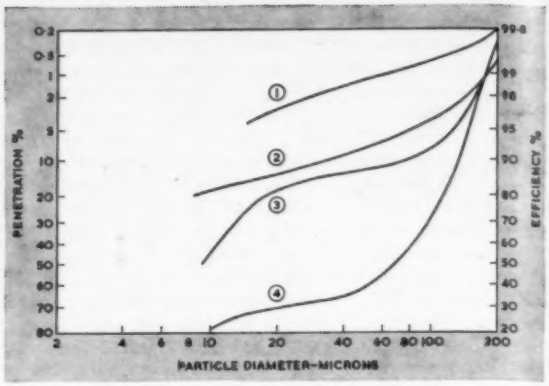


Fig. 7. Efficiencies of filter combinations.

compared with the spaces between the fibres. The life of such a filter is terminated when its efficiency has fallen to some predetermined value due to the loss of oil by evaporation from the fibres, or to the reduction of the effective areas of the fibres as their surfaces become covered in dust.

Since a low resistance to flow is essential in this application, the rising characteristic of the sieve type of filter is a series disadvantage, particularly in view of the large ballast component of the dust. In any case the efficiency of a sieve filter which has a pressure drop below the working limit (originally 7 mm Hg) is unlikely to be very high except perhaps for the largest of particles. For this reason straight sieve filters have not been used at Windscale, although, as will be seen in the next section, some of the impaction filters used have an inherent component of sieve action.

Filter Development at Windscale

Very little is known about the real performance of the filters used originally in the Windscale piles. The filter material, known as D type fibre, was of glass wool composition folded into corrugations as shown in Fig. 3, and was reported to have an efficiency of 99.5% for particles greater than 10 microns diameter. This claim was not substantiated in the laboratory, the measured efficiency being 85% for 4-micron particles but only 40% for 17-micron particles. Since the filter was used dry, this drop in efficiency was presumably due to blow-off and subsequent migration of the larger particles. It was intended that after a certain exposure in the stack, these filters would be washed and used again, but the greatest failing of the D-type filter was its readiness to tear into gaping holes, particularly at the corrugations, during washing so that after use the efficiency could approach zero. At this stage (early 1953) work was initiated at Windscale to find the best filter to deal with the conditions given in a summarised form earlier.

The gas temperatures involved precluded the use of filters made of paper and similar easily combustible materials and an answer was sought using glass fibres. Such material is comparatively cheap and is available in various forms and fibre diameters. Glass fibres also exhibit a reasonable amount of elasticity so that a loosely packed mat of fine fibres is readily compressible. It will be seen later that advantage is taken of this to improve filter performance by compressing a number of mats into a fixed frame depth.

Three different glass fibre filter materials have been used in the Windscale pile stacks. They are:

(1) Battery mat or Starch Bonded Staple Tissue—S.B.S.T. (Fig. 4). This consists of a random arrangement of glass fibres about 16 microns diameter, bonded together with starch and pressed into a sheet 0.02 in. thick with a packing density of approximately 0.06.

(2) "Fibreglass" coarse-fibred material (Fig. 5). Again a random arrangement of glass fibres, but this time about 230 microns diameter, bonded together with a resin and pressed into mats either ½ or 1 in. thick with a packing density of 0.03.

(3) R.50 material (Fig. 6). This is similar to the coarse-fibred material, except that the fibres are very much finer, originally having a diameter of 50 microns, the bonding is resin and the mats 1 in. thick, but the packing density is only 0.005. Later production material had a fibre diameter of 30 microns and a packing density even lower at 0.0044.

The fineness of the fibres gives a nap to the surface of the battery mat (Fig. 4 (b)), which behaves in the manner of an impaction filter; at the same time, the compression and bonding of a large number of fibres into a paper-thin sheet imparts to it a strong sieve action particularly for the larger particles. The two other filters listed are essentially impaction types because of the large spacing between the fibres.

The original D-type fibre filters mentioned previously were replaced at an early date after the start of the investigation by starch-bonded staple tissue. Two sheets of material were chosen as being the best compromise between filter performance and replacement rate as necessitated by pressure drop. For continuous replacement with a turn-round cycle of 10 days the mean pressure drop across the filter was 4-5 mm Hg, which allowed a further increase of about 2 mm Hg for unforeseen contingencies before reaching the permissible limit. In an attempt to take advantage of the impaction effect resulting from the nap surface, both layers of staple tissue were spray oiled prior to installation. Since an ordinary mineral oil was used for this purpose, it is doubtful whether much oil remained on the filters after a few hours' exposure to the hot air blast of the reactor effluent. The filter performance of two sheets of staple tissue for both dry and oiled fibres is given in Fig. 7.

Whilst the above filter was in use, development work was proceeding for the first of the impaction filters using coarse-fibred material. Filters using this material were essentially only an intermediate stage in the development of the later R.50 materials; for this reason, they will be dealt with briefly. Since one of the main advantages of an impaction filter over a sieve filter is its greater dust load for a given increase in pressure drop (about 20 times in this instance), the time that the filter will be required to be exposed to the gas stream will be considerably longer. Since also an impaction filter will operate satisfactorily only as long as an adherent layer is maintained on the surface of the fibres the choice of a suitable oil and the technique of

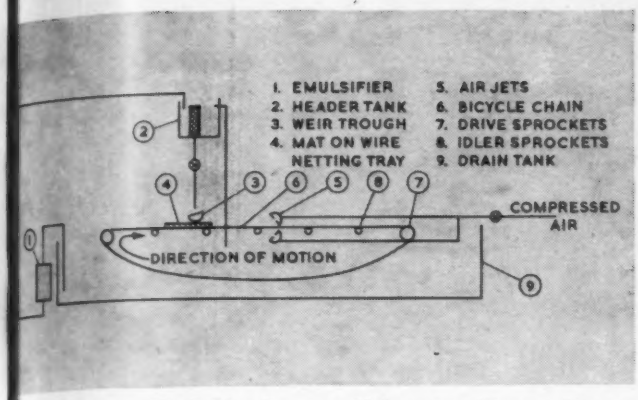


Fig. 8. Line diagram of laboratory oiling machine.

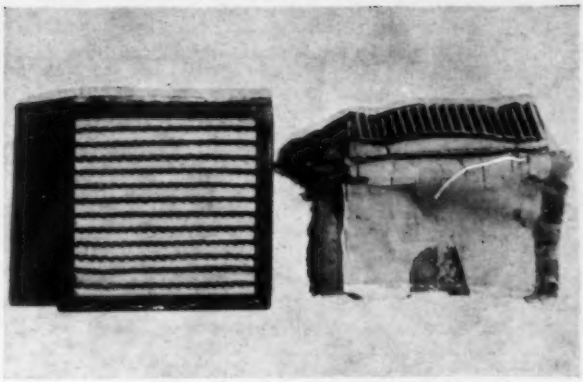


Fig. 9. Vokes dry filter.

applying it constituted an important part of the development programme. This will be dealt with in the next section. It is sufficient at this stage to say that the useful life of this filter in the stack was determined by loss of oil rather than increase in pressure drop, but by using a silicone oil a mean life of 6 weeks was achieved. The filters used consisted of three ½-in. mats of oiled coarse fibre material followed by a single sheet of dry S.B.S.T. This composite filter had a pressure drop of 4-7 mm Hg; in fact, very similar to that of the double-sheet S.B.S.T. filter which it replaced. The choice of three ½-in. mats was on grounds of ease of loading into the filter frames. The backing layer of S.B.S.T. was included to make full use of the allowable total pressure drop and at the same time to give a valuable sieve action safeguard against very large particles which might become re-entrained as the oil was lost by evaporation from the impaction filter or which might penetrate the filter because of a very low vertical approach velocity. The filter performance of this composite filter is shown in Fig. 7.

The next impaction filter to be adopted consisted of four 1-in. mats of R.50 material, again followed by a single sheet of dry S.B.S.T. In this case, due to the compressibility of the R.50 material any desired number of mats could be accommodated in the frames, the choice of four being determined by pressure drop considerations. The composite filter had a total initial pressure drop of about 6-6.5 mm Hg which, although rather near to the maximum permissible value of 7 mm Hg, was considered satisfactory in view of the small rate of rise of pressure drop with dust load for this type of filter.

Rather ironically, each increase in filter efficiency added to the difficulties of oiling the material by spray gun, since the oil droplets were less able to penetrate into the body of the filter material. Doubling the mat thickness to 1 in. for the R.50 material to meet manufacturing requirements made matters still worse and a completely new oiling technique had to be developed. However, a trial loading of the R.50 composite filter was installed in Windscale pile 1 filter gallery and despite the imperfect oiling of the mats a useful life of about 6 weeks was realised. The performance that would have been achieved with satisfactory oiling is also shown in Fig. 7.

The Oiling of Impaction Filters

It has already been stated that an impaction filter will only perform satisfactorily as long as an adherent film is maintained on the surface of the fibres. Where oil is used for this film, it must have a sufficiently low vapour pressure to avoid early loss by evaporation and must also be able to withstand the gas temperatures without oxidation or similar deleterious chemical change.

At the outset it was clear that the mineral oil that had been used for oiling the sheets of staple tissue would be unsuitable for an impaction filter. Apart from its excessive rate of loss by evaporation, it is not particularly suitable chemically for prolonged exposure in an air blast at a relatively high temperature. A silicone oil with its superior chemical stability was an obvious choice. A grade having a viscosity of 1000 centistokes, suitably thinned with toluene, was found suitable for spraying the ½-in.-thick mats of coarse fibre material. The advent of the higher efficiency 1-in.-thick mats of R.50 material presented a new problem. Two methods of oiling the material were tried—dipping and spraying—both in a 20% V/V solution of silicone oil, MS 200, 1000 c.s grade, in toluene. Despite the difficulty of ensuring adequate penetration, even with spraying from both sides, spraying proved to be the superior method, giving a very much more even distribution of oil over the mat and certainly a more controllable total quantity on it. Many measurements of efficiency and variation of pressure drop with dust load were made on mats oiled in this way.

At this stage it became clear that if full advantage were to be taken of the long life offered by the large dust carrying capacity of the R.50 material a silicone oil of even lower vapour pressure than that of the 1000-c.s. grade was required. Such an oil was available, but its viscosity of 12,500 c.s. made satisfactory oiling, either by dipping or spraying in a toluene-thinned oil, unattainable. So much toluene was required to thin the oil to a manageable viscosity that the oil content was insufficient to give an adequate oil deposit on the fibres after the evaporation of the solvent. Neither was it possible to increase the thickness of the film by repeated dipping or spraying, since each application of the solvent-thinned oil washed off the oil usefully deposited the previous time.

A new oiling technique was developed at Windscale in which the viscous silicone oil was emulsified with a water content of 40% by weight using Lissapol NDE as the emulsifying agent. The line diagram of Fig. 8 shows the layout of the scheme. The emulsifier pump is used as the power source for circulating the emulsion round the system. The emulsion flows over a weir and pours under gravity through the slowly moving filter mat. The mat continues under powerful air jets to remove surplus emulsion and finally is allowed a period for the water to evaporate and leave the oil behind on the fibres. The advantages of this technique are:

(1) All fibres are soaked in emulsion so that the difficulties of incomplete penetration are eliminated.
(2) An emulsion of manageable viscosity can be made from the most viscous silicone oil.
(3) The oil is deposited uniformly throughout the entire

filter mat and the quantity is easy to control.

(4) Where the desired quantity of oil is greater than can be deposited in a single pass, the mats can, after final drying, be put through the machine again. Oil already deposited is not washed off by subsequent applications of emulsion as is the case with a toluene-thinned oil.

(5) It is much safer and cheaper than using inflammable or toxic organic solvents.

A laboratory mock-up of a machine employing the above technique was used to oil mats of R.50 material on which the measurements given in the next section were obtained.

Improvements in Filter Performance Following an Increase in Permissible Pressure Drop

The maximum permissible pressure drop across the filters in the Windscale piles was originally determined largely from considerations of plutonium production loss. This factor, in conjunction with a maximum effective thickness of about 1½ in. for the filter material in the existing frame, set an upper limit to the performance of any filter that could be used in the Windscale piles. As part of the inquiry following the Windscale incident in October, 1957, an assessment was made of the improvement in filter performance that would result from an increase in the pressure drop that could be tolerated across the filters. Even ignoring plutonium production loss, there is still a limit beyond which it would be unreasonable to take the value of the pressure drop permitted across the filters. Based on structural limitations and the necessity to maintain a positive differential in the filter gallery used by personnel, this limiting pressure drop is about 15 mm Hg.

Since this value is twice the original pre-incident limit, an R.50 composite impaction filter having twice as many elements as used formerly is possible. Such a filter, consisting of eight nominally 1-in.-thick mats of R.50 material followed by two sheets of starch-bonded staple tissue, could reasonably be loaded by hand into the existing 2-in. frames after slight modification to the lid. Apart from the improved performance resulting directly from the use of a greater thickness of filter medium, the degree of compression required produced a very efficient seal round the edges of the mats.

Another result of raising the permissible pressure drop was that a Vokes dry filter became a contender. This filter consists of a layer of superfine glass fibre material backed with a layer of LOH glass paper, the whole being pleated to give a gain in area of about a factor 10 (Fig. 9). Although somewhat similar to the original D-type filter, the extra permissible pressure drop has enabled the glass paper backing to be included in the filter make-up which, together with the greater resilience of the superfine fibres, should have overcome the main disadvantage of the pleated filter—namely, the tendency to tear at the folds. Since this dry filter has a performance as measured in the laboratory comparable to that of the composite R.50 impaction filter, the two will be dealt with simultaneously.

Pressure Drop and Dust Loading Tests

The variation of pressure drop with airflow was measured over a range of approach velocities from 100 to 1000 ft/min.$^{-1}$ for air at room temperature. These results, given in Fig. 10, show that for the approach velocity encountered in the filter gallery, about 900 ft/min.$^{-1}$, the two filters have a similar pressure drop. The gas velocity through the filters is only half that in the stack due to the gain in filter area in the gallery. For true stack conditions the elevated temperature in reducing density will decrease the mass flow and hence pressure drop for a given approach velocity. A check of this has been made in a smaller rig which could be operated at 150°C. The effect of this temperature increase

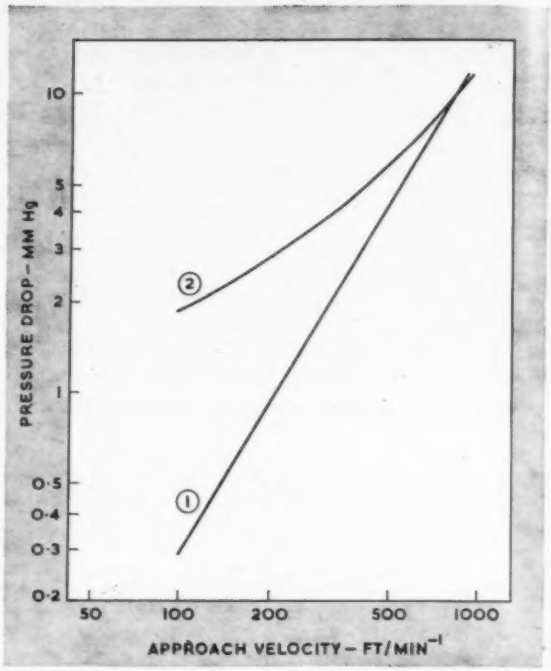


Fig. 10. Variation of pressure drop with airflow.

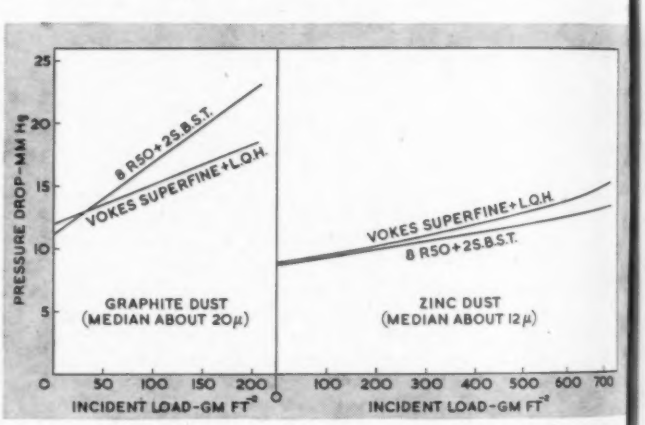


Fig. 11. Variation of pressure drop with dust load.

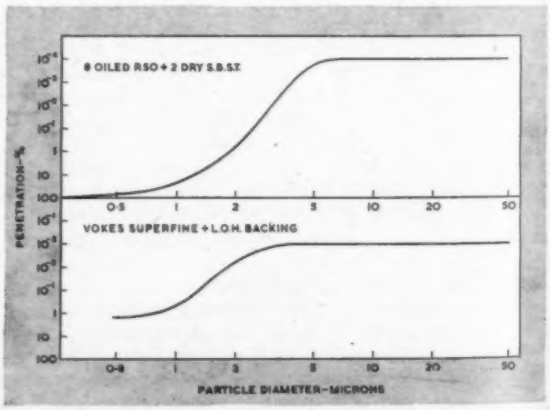
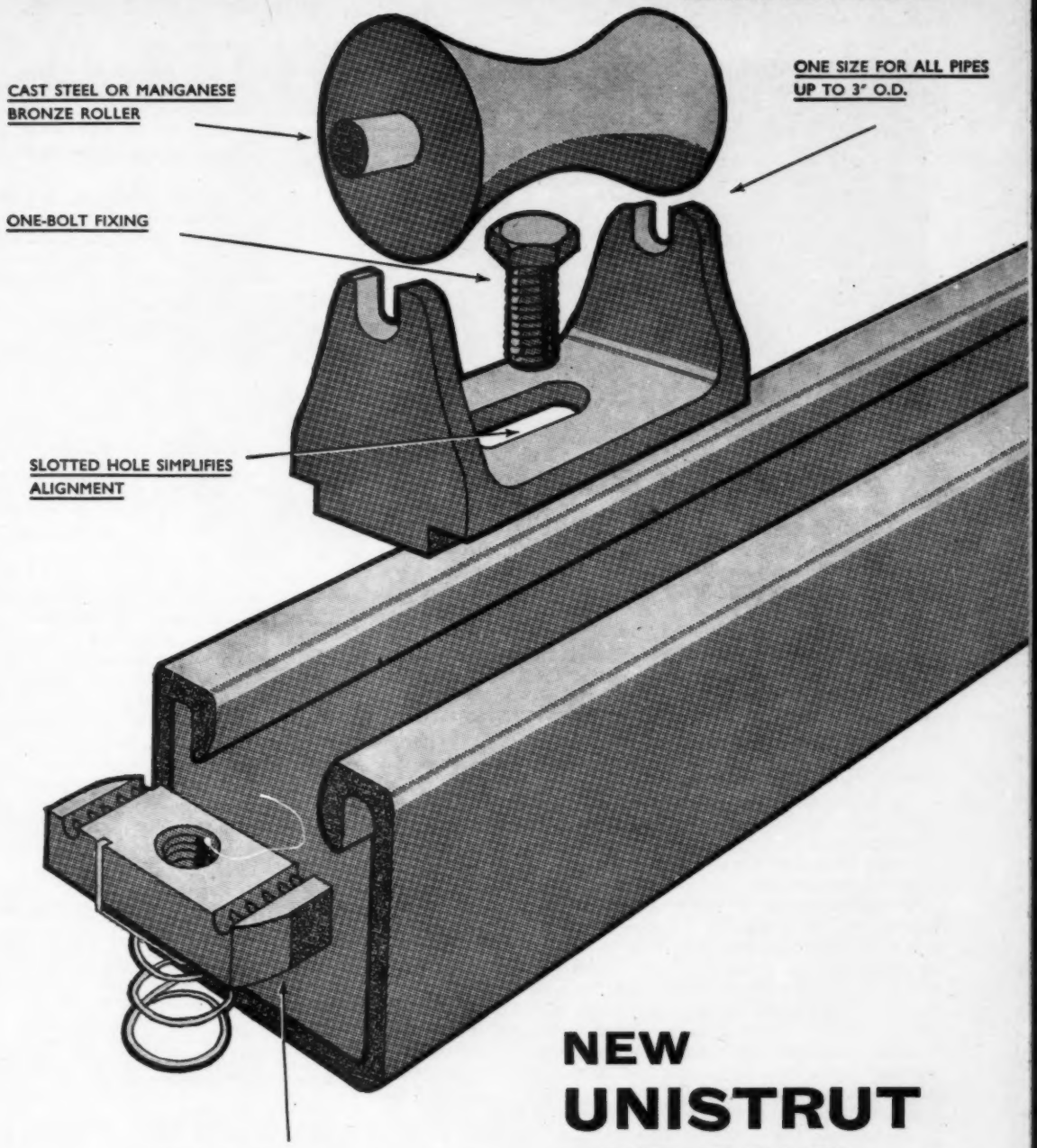


Fig. 12. Intrinsic efficiencies; clean filters approach velocity 900 ft/min.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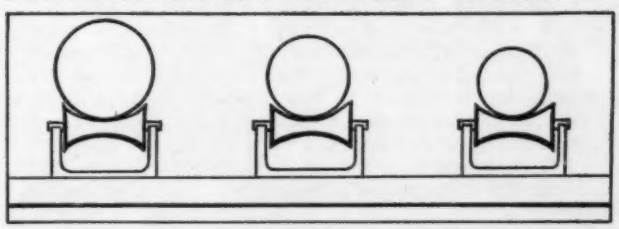

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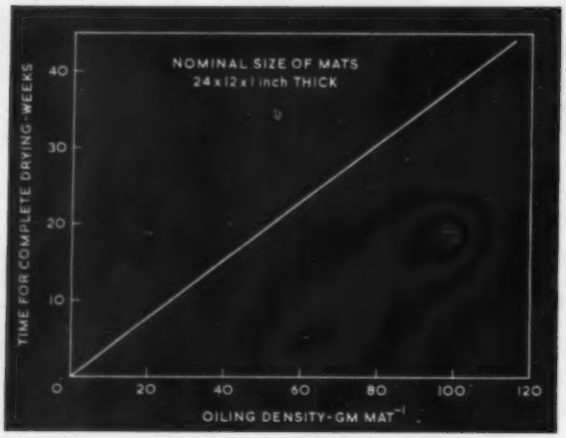


Fig. 13. Relation between drying time and oiling density.

was to reduce the pressure drop of the Windscale filter by a factor 0.7 and that of the Vokes filter by a factor 0.8.

Loading measurements were made using graphite machinings with a median size of about 20 microns and with zinc dust of median size about 12 microns. The results are shown in Fig. 11. The apparent difference in loading capacity for graphite and zinc dusts is largely accounted for by the different densities and sizes of the two dusts. Clearly, the pressure drop is influenced only by the number of particles of a given cross-sectional area that have been stopped, their individual weights being of no importance.

Penetration Measurements

In the Windscale laboratories copper has frequently been used as a substitute for uranium oxide in penetration measurements. It has a similar density, it can easily be estimated chemically, it can readily be made slightly radioactive when desirable, and is less of a health hazard; but the direct measurement of very low penetrations is not easy. Thus for a filter with a penetration 0.001% at 50 microns, the 50-micron copper particles used will each have a mass of 0.5 μgm, so that with a limit of detection of 50 μgm, i.e., 100 particles collected downstream, it will have been necessary to have applied an incident load of 5 gm for this penetration to be just measurable. Fractional downstream sampling would necessitate proportionally greater incident loads. Thus the statistical errors and the possibility of the load affecting filter performance make direct measurement a method to be avoided if possible.

Fortunately, the Windscale filter can easily be separated into its component layers which enabled its penetration to be measured by the indirect method of measuring the distribution through the filter of previously sized copper dusts. The Vokes filter, however, cannot conveniently be split into layers and penetration measurements had to be made directly by collection on the downstream side.

Measurements of penetration on both filters were also made in the laboratories of Vokes Ltd. of Guildford. For these, mixed-sizes zinc dust was used with cascade impacters upstream and downstream of the filter, and the filter became rather heavily loaded in the course of the experiment. Methylene blue penetration measurements on both filters were also made at Guildford.

All the results from both sources have been used to define the curves of intrinsic efficiency of the two filters shown in Fig. 12.

Variation of Penetration with Exposure

The penetration of the filters will increase with time of exposure to the stack gases through two causes: namely, the blow-off of particles as the dust load steadily increases and the drying of the oil adhesive. The latter will only apply to the Windscale filter which has an estimated variation of oil life with the quantity of oil initially on the mats as shown in Fig. 13.

Due to lack of sensitivity in the methods used for detecting downstream particles, it has not been possible to make an accurate laboratory determination of the blow-off rate. However, using the very approximate measurements that 10^{-3} to 10^{-4}% of the dust already on the filters would blow-off per day, it can be concluded that both the Windscale and Vokes type of filter would have a useful life of some 20-30 weeks. A real assessment of filter life can only be made by actual exposure in the stack. This unfortunately is no longer possible at Windscale.

Conclusions

Over a period of about six years work at Windscale has resulted in a considerable improvement in the performance of the filters used in the pile stack effluent. Although the actual figure depends on particle size, replacement of the starch-bonded staple tissue filter by the coarse fibre type reduced the number of particles escaping for constant effluent conditions by a factor of approximately 3. The next filter to be used, consisting of four 1-in. layers of fine fibre R.50 material and a layer of staple tissue, would have given a further reduction of about a factor of 3 when the oiling technique being developed at that time had been adopted. Resulting from the decision, following the Windscale accident of October, 1957, to raise the permissible pressure drop across the filters by a factor 2 the greatest single improvement in filter performance thus became possible. Using either a fine fibre filter of the type just developed but with twice as many elements or a dry type of filter of superfine fibres which became a possibility at the increased pressure drop, the number of particles escaping could be reduced by no less than a factor of 100-1000.

In addition to these obvious advances in filter performance, improvements had also been made in other directions. The latest filters, for example, were able to hold an increased dust load before replacement became necessary. This extended life of some 20-30 weeks would greatly reduce the radiation exposure of the personnel handling the disposal of the discharged filters.

ACKNOWLEDGMENTS

The author acknowledges a free use of the internal reports of his colleagues, D. Jakeman, now of Birmingham University, and E. J. Higham, from which experimental results and diagrams have been abstracted.

CORRECTIONS TO PRESSURE DROP LOADING

IT has been brought to our attention that a number of points in the article on "Pressure Drop, Loading and Flooding in Irrigated Packed Towers" by H. E. Edulgee published in the May 1960 issue, p. 330, were incorrect as published.

The errors in question were as follows:

For point in line three of the second column, p. 330 read points.

For α_G, α_L in line 17 of the first column, p. 332 read ρ_G, ρ_L.

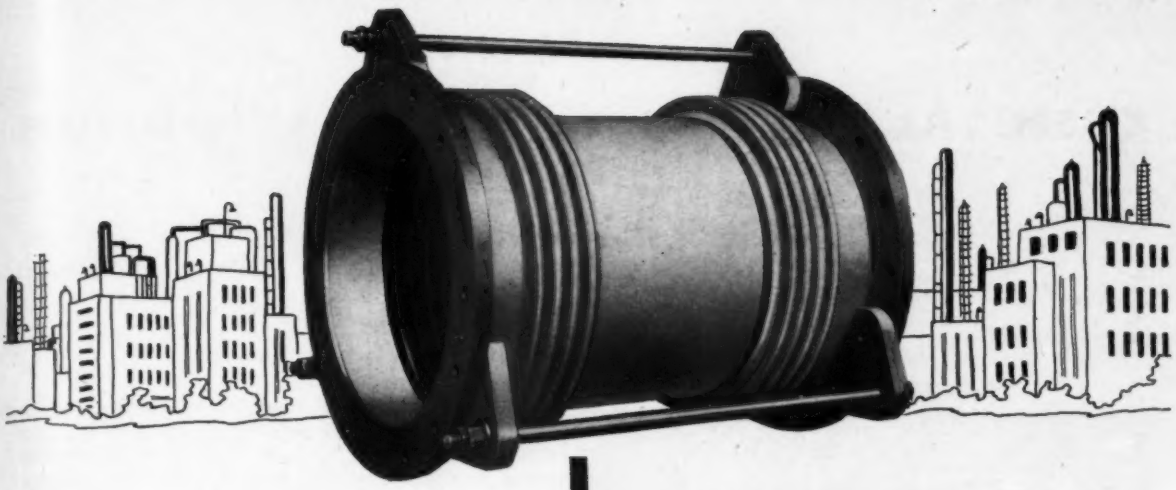
For α_G, α_L in line 19 of the first column, p. 332 read ρ_G, ρ_L.

For α_G, α_L in line 23 of the first column, p. 332 read ρ_G, ρ_L.

For G in line three of the second column of p. 333 read L.

BCE 7635 for further information

The use of BELLOWS in Chemical Engineering



Wherever pipes operate under conditions of temperature and pressure, expansion joints may be required. The bellows type expansion joint has in the past few years become standard equipment, being now recognised as extremely efficient. Teddington engineers have played a leading part in the introduction of stainless steel bellows expansion joints to the chemical industry and can be relied on to co-operate fully with design and plant engineers who are confronted with pipe problems.

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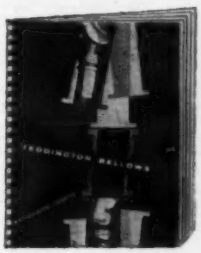

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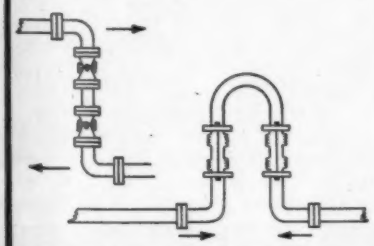

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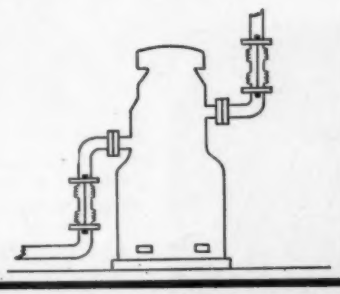

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M 62

CHEMICAL PROCESS HAZARDS SYMPOSIUM

The North-western Branch of the Institution of Chemical Engineers holds a conference on safety in design

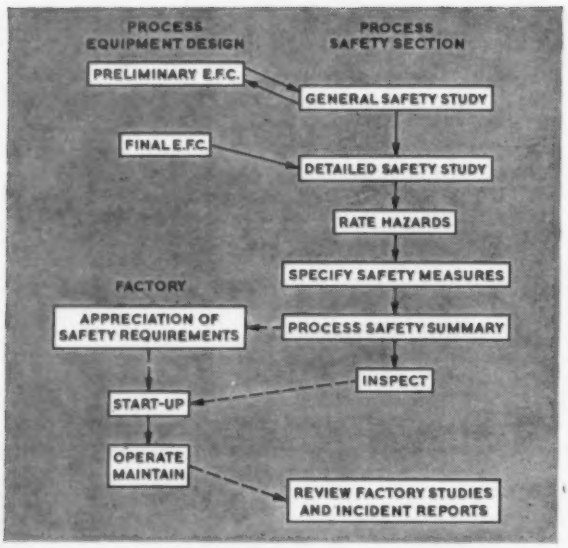

Fig. 1. Outline of procedure for study of a process plant safety given by Hall-Graggs, Robb and Thackara.

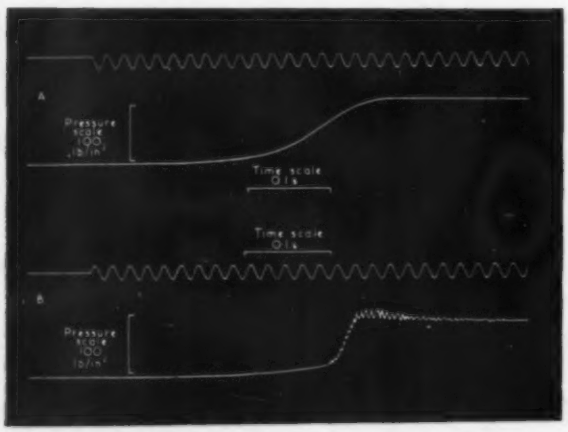

Fig. 2. Explosion pressure-time records for pentane-air mixtures in a 60.6-cu.-ft vessel. A: 2.7%, B: 3.5% pentane. Given in a paper presented by Burgoyne and Wilson.

A THREE-DAY symposium on "Chemical Process Hazards with Special Reference to Plant Design" was held at Manchester from March 29 to 31 by the North-western Branch of the Institution of Chemical Engineers. The first paper was presented by Dr. D. Matheson, of H.M. Factory Inspectorate, who described some accidents that are typical of those which led to certain precautionary measures given in this paper. The worst gassing accidents may occur to men working inside the plant or confined spaces. Ingress of fumes must be prevented and the isolation of plant or space must be very efficient. No other precautions can take the place of disconnection and blanking off; the space should be tested by reliable chemical means. Sludges are insidious and unpredictable in their behaviour, and breathing apparatus and life-lines are just as necessary in the presence of sludges.

Explosions should be prevented by avoiding flammable mixtures of a material with air and by precautions to limit the spread and effects of an accidental explosion. Accumulations of dangerous dusts must be avoided. Metallic powders are particularly dangerous, and apparatus in which explosion is a danger should be in the open air. Explosions in bucket elevators inside a factory can start secondary explosions in a number of storeys of a building. Fires are prevented by safe storage of flammable liquids; similar precautions should be taken with the same liquids in the process plant.

"An Approach to the Problem of Process Hazards in Plant Design" was made by Hall-Graggs, Robb and Thackara, whose paper was concerned with safety in the manufacture of soaps, detergents and other materials. In such processes the output of a unit is large; therefore, reliability and freedom from accidents are paramount. The Process Safety Section is part of the Engineering Division: they guard against overpressure, fire and explosion; they recognise, evaluate and remove, if possible, all the hazards or guard against those that cannot be removed; they see that safeguards are installed, work properly and are maintained thereafter; and they consider the effect of process changes on safety. New projects are studied by this section; materials, reactions, the proposed plant and their dangers are studied; hazard sheets are prepared for each item; the hazards are rated in order of likelihood and danger; and protection measures are listed for each hazard. A process safety summary is prepared, an inspection of the new plant is made and the safety equipment is tested.

Mr. A. H. Isaac in his paper "Automatic Control and Instrumentation for Hazardous Processes" excluded safety and non-return valves, bursting discs, safety seals and torque shear pins which are limiting devices. Instead, he indicated how instrumentation is applied to reduce or avoid serious

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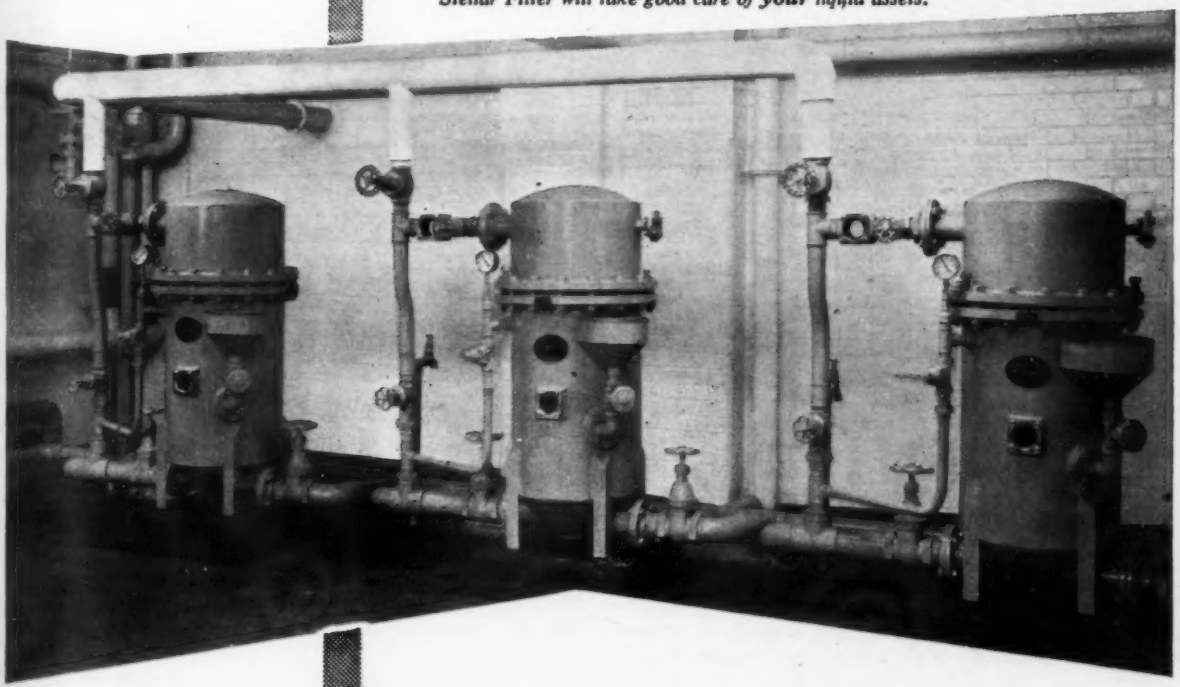

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dangers in continuously operating plants. The thickness of the metal of plant designed for pressure work is non-destructively examined and tested as a check on corrosion, but the tests cannot be applied continuously. Tests on rotary machinery indicate the development of failure before the onset of serious consequences. Hazards may arise because of the failure of services such as steam, water, fuel and electricity. The consequences of failure can be so serious that the process needs interlocked shut-down operators to safeguard the plant. Immediate action is needed to shut-down a plant when there is a departure from designed operating conditions such as the momentary failure of oil to feed a lighted burner or a furnace which will rapidly fill with an explosive mixture unless action is taken. Plants carrying out large-scale catalytic oxidations of naphthalene, methyl-alcohol and NH_3 pose similar problems.

Human error is responsible for many accidents on plants, and automatic process control removes much of the responsibility for detailed operation from the operator, but the greatest hazards occur during the start-up before automatic control takes over. Any plant operating a potentially hazardous process under design conditions is safe. To maintain these conditions, instruments measure and present information on pressures, temperatures, flows, levels and other properties at various points in the process. The operator is enabled not only to assess conditions at the significant operating regions of the plant but also at extraneous points and in ancillary units to ensure that hazardous conditions do not arise there. The information may be centralised to a locality remote from the plant which may be operated from this locality, but this places great emphasis on the completeness and reliability of the instrument readings. If the reactions are only partially instrumented, the measuring equipment is centralised near the plant to enable the operator to supervise visually the equipment and operate it manually. Visual examination is necessary in a number of cases; for example, the observation of conditions of solids on a conveyor belt and their discharge from a chute, or the characteristics of flames.

Instruments have a time of response to changes to which they often give diminished values; therefore, there is likely to be danger unless their performance is matched with the alarm conditions; great care also must be taken to position the instruments to yield the most satisfactory results.

The automatic controller is a blind device and has a limited flexibility to deal with exceptional operating conditions; therefore, it may aggravate the situation in those circumstances. The flexibility can be increased by sequence control valves, cascade control systems and other arrangements which even take care of failure of the control system.

The alarm system must identify the nature and location of the hazardous condition. A complete safety system, by an interlocked system, automatically shuts down all or a part of a plant. Safety and alarm systems were described in detail.

A paper on "The Relief of Pentane Vapour Air Explosions" was presented by Dr. J. H. Burgoyne and Dr. M. J. G. Wilson, who obtained information on the area of relief being related to the cross-sectional area of the vessel. Explosions were made in an adapted marine boiler shell, volume about 200 cu. ft, and more explosions were made in a volume of 60 cu. ft when the major part of the larger volume was filled with sandbags and walled off. Holes in the 60-cu.-ft vessel were three 18 in. diam. along one side and one 24 in. diam. at the end; they could be used as open vents and they were flanged so that orifice plates, relief closure devices or blank flanges could be attached. Pentane was added to give a concentration of up to 3.5% pentane in the air in the vessel, the whole mixed by a fan, ignited opposite the 18-in. holes and pressure-time records made. For the 200-cu.-ft. vessel, one more 18-in. diam. vent in the mid-position along the side was added. A 3.5% pentane mixture produced the greatest rate of pressure rise, but the 2.9% pentane mixture gave the maximum burning velocity. A spherical flame front gives the minimum rate of burning; any disturbance by turbulence or by the opening of a vent increases the rate of burning. A vent near the source of ignition is more effective in lowering the peak pressure than one at a distance. A closure that opens smoothly at a certain pressure, such as a plate valve, gives a lower peak pressure than a diaphragm which bursts open at the same opening pressure.

Dr J. H. Burgoyne and K. E. Bett and Mr. R. Muir discussed "The Explosive Decomposition of Ethylene Oxide Vapour under Pressure". Ethylene oxide is capable of propagating a decomposition flame if ignited and if its pressure is above atmospheric. More than 3% ethylene oxide in air can provide an explosive mixture; nitrogen will suppress the explosive decomposition.

A vessel made entirely of austenitic stainless steel and capable of withstanding 1500 psig was used in the experiments. Mixtures of nitrogen or other diluents and ethylene oxide were ignited in the vessel by a nichrome wire, and pressure-time measurements were made. All the materials were of commercial qualities. Experiments were made at 125°C and 150 psig and the percentages by volume of nitrogen, ethylene, propane and butane necessary to suppress the decomposition of ethylene oxide were plotted against the partial pressure of ethylene oxide vapour in the gas before ignition. Whereas the lower limits of explosibility of ethylene oxide in nitrogen and in ethylene increased with increase in the partial pressure of ethylene oxide vapour, these limits were constant with increase of the partial pressure of ethylene oxide in propane and butane. Temperature had little effect on the lower limit of explosibility of ethylene oxide in nitrogen.

The observed limit for flame propagation in a mixture of ethylene oxide and inert diluent depends on the energy of the igniting source. The ratios of maximum explosion pressure to initial partial pressure of ethylene oxide and of the final pressure after explosion to the initial partial pressure of ethylene oxide both increase with pressure.

Ethylene oxide may decompose into methane, carbon monoxide, ethylene and hydrogen. A much larger volume of nitrogen was required to suppress the ethylene oxide decomposition than had been found by previous workers. Although propane and butane are the most effective diluents in suppressing the explosive decomposition of ethylene oxide, in practice their use is restricted because they dissolve in ethylene oxide.

"Explosion Hazards in the Manufacture of Terephthalic acid" was presented by Dr. D. H. Derbyshire. Terephthalic acid is prepared by the oxidation of *p*-xylene by nitric acid. This is a batch process; *p*-xylene and nitric acid are introduced into an autoclave, are heated by steam to the operating conditions of pressure and temperature, the evolved gases, which are nitrous and nitric oxides, steam, nitrogen and carbon dioxide, are passed to a condenser and the condensed material returned to the autoclave. The uncondensed gases pass through the control valve which controls the pressure in the autoclave and are stored in the buffer tank with gases from other autoclaves in the process. Gases from the buffer tank are mixed with air and passed to the oxidiser-cooler, where nitric oxide is oxidised to nitrogen dioxide which is absorbed in an absorption tower to give nitric acid. Nitrogen oxides from the oxidation support the combustion of *p*-xylene and there is a risk of vapour-phase explosion in the autoclave, condensing system, buffer tanks and oxidiser-cooler. There is a danger of a liquid phase explosion in the oxidiser-cooler.

The approach to safeguarding the plant has been to

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operate it so that vapour spaces of the various units are filled with non-inflammable gas, or, when this is impossible, to design the plant so as to minimise damage from an explosion. Safety in the autoclave is obtained by operating at such a temperature that the amount of steam in the vapour phase is sufficient to prevent an explosion. This is impossible in the condenser to which vents are fitted to minimise the damage caused by an explosion and to prevent explosive pressures reaching the autoclave. The *p*-xylene in the gas that passes to the buffer tank is measured, and if it exceeds a lower limit of inflammability, inert gas is injected and the plant closed down. The oxidiser-cooler is self-draining to the absorption tower. The safe temperature in the autoclave was determined by the limits of inflammability of *p*-xylene in the most dangerous gas (this gas contains the maximum ratio of nitrous oxide to nitric oxide—see Fig. 3) and investigating the effect of steam on these limits. The condensers were designed to withstand the maximum explosion pressures, and bursting discs prevent dangerous pressures being transmitted to the autoclave. Each autoclave and condenser is isolated inside a separate blast cubicle.

P-xylene in the gas to the buffer tanks is determined by measuring the rise in temperature of a catalyst bed which oxidises this material. No explosive organic material can accumulate in the oxidiser-cooler because the cooler drains to the absorption tower in which the concentrated acid dissolves the nitro-compounds.

"The Design of Explosion Reliefs for Industrial Drying Ovens" was given by Dr. W. H. Simmonds and Mr. P. A. Cubbage. Articles are heated in ovens to evaporate a solvent which is carried away in a stream of air. The mixture is often explosive. Ovens may be continuously or batch operated and are called either conveyor or box ovens, the latter causing many more deaths from explosions than the former. Box ovens usually consist of a metal surround to a heated region through which air is drawn by natural or forced convection; they are usually rectangular in section and doors form nearly all one side. The ovens are heated by bar burners along the bottom of the oven; they range between 10 and 600 cu. ft and are usually nearly cubical in shape. Experiments were made with empty box ovens having vents as explosion reliefs. The ovens were filled with vapour and air mixture which was ignited and the pressure rise was measured. For a number of vapours the mixture producing the most severe explosion was proportional to the normal combustion velocity of the mixture, town gas having the highest flame speed and vapours the lowest. Heated vapours produced pressures similar to town gas; therefore, most experimental work was done on town gas at a concentration giving the greatest pressure which always developed when the gas was ignited at the centre. A short delay after ignition was followed by a rapid increase in pressure, the relief was ejected and the pressure fell, then rose rapidly to a greater maximum than the first one; this is caused by a rapid increase in the spherical surface of a flame. The relief was hurled from the oven when the pressure was many times the pressure necessary to balance the weight of the relief. Combustion was still proceeding at a rapid rate. Venting may occur at such a large flow that there is a large pressure drop at the vent and pressure increases again in the oven. The relief should be located centrally in the side of ovens; shelves, even a metal grid shelf, cause a great increase in pressure for explosions ignited below the shelf. Therefore, there must be side reliefs if shelves are fitted and the sides of the ovens should be a certain distance from the walls of a building. Interlocked pressed steel construction is flexible and superior to the old type of oven having sheet metal firmly bolted to a heavy angle iron; the former are less liable to disintegrate than the latter.

The next paper, "Relief of Explosions in Duct Systems",

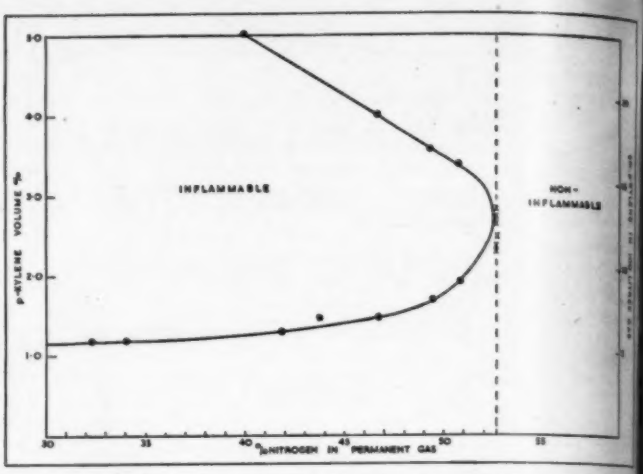

Fig. 3. Effect of nitrogen on limits of inflammability of p-xylene in a mixture of nitric oxide and nitrous oxide ($NO:N_2O$) at atmospheric pressure. Presented in the paper given by Derbyshire.

was presented by Dr. J. Rasbash and Mr. Z. W. Rogowski. Ducts frequently convey flammable vapours and gases and it is possible that an explosive mixture might become ignited. The maximum pressure of an explosion in a short duct is about 100 psi and rises to 1000 psi in a long duct where detonation may occur. The temperature of the gases passing through the flame is about 2000°K. If the hot gas cannot expand through a vent, it will establish a local pressure rise which will accelerate the flame and the unburnt gases downstream; these unburnt gases become turbulent and the rate of combustion at the flame front is increased The duct can be provided with relief vents to keep the explosion under control and the pressure at a certain maximum. Propane and pentane were used in experiments as typical gases; they were mixed with air and allowed to become stationary before the mixture was ignited by an induction spark. The ducts, 3 in. or 6 in. diam., or 1 sq. ft, were limited to straight lengths, or straight lengths containing either a central orifice as obstacle or a central strip across the duct, a T-piece or a bend. The vents consisted either as an open end to the duct or as loose covers weighing 250 g. per sq. ft, or thin polythene sheeting clamped to the edges of the vent, or by light covers weighing 270 g. per sq. ft of vent area clamped to the duct by magnets. With an open end in a straight length of duct, ignition near the vent gave much lower pressures and flame speeds than did ignition remote from the vent. Flame speeds increased as the ratio of duct length to duct diameter increased and as the size of the vent increased. In the presence of obstacles, the flame propagated in a normal manner up to the obstacle, but immediately downstream of the obstacle there was a rapid rise in pressure and the maximum pressure was proportional to the resistance to fluid flow by the obstacle. A vent near the ignition source reduced the violence of the explosion. Supplementary vents of 250 g. per sq. ft were placed in the square duct which was open at one end and had an ignition point at the closed end; small but frequent vents were more effective than fewer large vents and there was a marked reduction in flame speed as the flame passed a vent. Slots with loose covers kept the explosion pressures low; when the covers were replaced by polythene sheet clamped to the duct or by light covers clamped to the duct by magnets, most pressures remained below 2 psig, the maximum allowable for weak ducts. When the vents were closed by polythene, which is the most likely cover for slot vents, the square vents were more efficient than the

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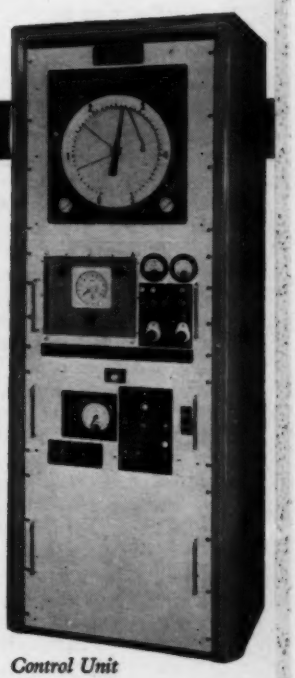

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slot vents. In all experiments with vents closed by magnets and placed near to the source of ignition, a vent cover was removed very early in the explosion and, when there were no obstructions, some of the other vent covers were not moved as the explosion passed along the duct. In principle, the best way of distributing a given area of venting is by a slot running the whole length of the duct; any closures should be held in place by springs, magnets or weights, where, for a given restraint on the closure, the pressure to dislodge the closure would be independent of its shape.

The next paper, "The Quenching of Flame by Perforated Sheeting and Block Flame Arresters", was presented by Mr. K. N. Palmer. Most flame arresters or flame traps consist of a solid matrix containing a group of small, narrow passages or apertures through which gases or vapours can flow but which are intended to be too small for a flame to pass through. As the flame enters the arrester, it is subdivided into flamelets, which should be quenched if the flame is not to propagate to the opposite side of the arrester. The various types of arrester differ in the way this subdivision is obtained and in the number and size of the apertures. Common types include wire gauzes, perforated sheetings, crimped metal ribbons, sintered metal and towers packed with pebbles and Raschig rings; they differ considerably in their resistance to gas flow. Brass blocks, 1 cm thick and perforated with circular holes, and sheetings of various thicknesses were subjected to ignited propane—air mixtures of 4% and 2¼% propane. The velocities of the flames were measured just before they met the arrester which was placed in a circular tube. The blocks could be separated by a perspex ring or they could be in contact with each other. When the flame reached the arrester its velocity relative to the gas was considerably less than its velocity relative to the tube. The ability of the arrester to quench the flame depends on the velocity of the approach of the flame, or the diameter of the holes, the smaller holes being more efficient, and on the rate of heat transfer to the arrester from the blazing gas, wire gauze and perforated metal sheeting are effective only against slow-moving flames. For high-velocity flames perforated blocks are likely to be impractical and crimped metal should be considered.

"Hazards in Handling Acetylene in Chemical Processes, particularly under Pressure", was given by S. A. Miller and E. Penny. The main hazard is explosive inflammation either in the plant or through leakage outside it. The explosive limits lie between 2.5 and 80% of the gas in air. The plant must be adequately ventilated and the electrical gear be isolated from the plant. Acetylene can decompose into its elements and, under conditions of no heat loss, the products are raised to 3100°C during the reaction. After an explosion at Hüls it is now known that progressive decomposition of acetylene can take place at atmospheric pressure and deflagration can proceed to detonation if the pipeline is long enough. Such an accident can be confined to the pipeline by putting a tower in the line; this tower is packed with Raschig rings which are irrigated with water. This packing will quench deflagration or detonation in the first few inches, but a pressure wave will pass up the tower. Bursting discs in a pipeline will not prevent the build-up of a detonation wave because the velocity of the flame front is so great. Nitrogen acts as a suppressor, but so much of it is required that manufacturing processes using acetylene would work under a handicap. Sintered metal hollow expanders will act as a detonation arrester and, in a pipeline, steel wool plugs, 1 in. long compressed to a porosity of 75%, were always effective in suppressing detonation. Reactors using acetylene should be designed for a test pressure of 12 times the working pressure. Although bursting discs have a limited use with acetylene, they may limit a pressure rise in reactions with gas and liquid phases. The explosion temperature for acetylene in clean apparatus is 425-430°C and this is reduced to 280-300°C by the presence of powders. Copper and silver must not be used in any plant or apparatus, but valves with metal-to-metal sealing now seem safe to use.

Mr. K. M. Hill and H. Knott presented "The Design of Plants for Handling Hydrofluoric Acid". Hydrofluoric acid is toxic, corrosive, boils at a low temperature and produces severe burns on man. The limit of concentration of the vapour in the plant should be 2 ppm in air. Data for this paper were obtained for the design and from the operation of the hydrofluorination reactors and the hydrofluoric acid rectifying unit attached to the experimental fluidised-bed unit for the production of uranium tetrafluoride at Springfields. The reactors use gaseous hydrofluoric acid at temperatures between 200°C and 450°C to give a tail gas varying between 0 and 100% hydrofluoric acid; this is recovered as the azeotrope containing 37.5% acid, boiling point 112°C. For hydrofluoric acid over 75% concentration Monel metal or carbon steel is used and for concentrations lower than this copper and Monel metal are satisfactory. Cold anhydrous HF is stored in carbon steel vessels. Silver is satisfactory for HF in the presence of oxidising agents.

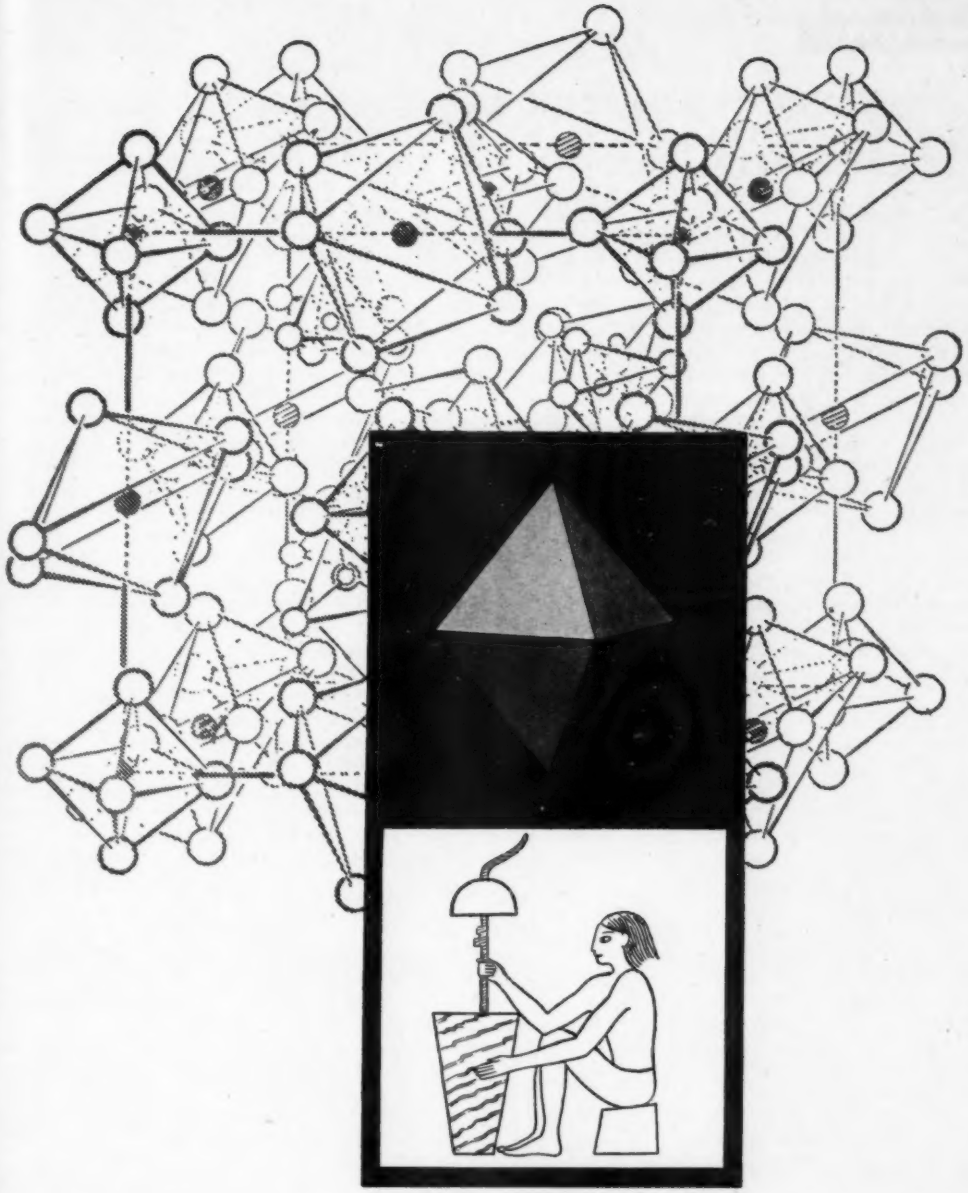
The first consideration in the design of any plant using hydrofluoric acid is to cope with corrosion. This problem is simplified by the use of HF over 70% concentration or under 20%. If reactions can be carried out in the vapour phase well above the dewpoint, corrosion will be decreased. An open-type plant can be worked when the amount of HF that may be released from a failure is small as in low-pressure plants with a small liquid hold-up, but an enclosed plant is necessary when corrosion is severe. The enclosure may be built to contain the leaks, but the enclosed cells must be adequately ventilated to a scrubber which will deal with the largest possible leak. In both plants the operations should be remotely controlled from rooms with good ventilation. Oxidising agents and oxygen should be eliminated from the process and plant design should allow for a blanket of inert gas such as nitrogen. The process should be continuous, the design of the vessels should be simple. Avoid branches to vessels if possible and do not use castings because they contain sand. Inconel high-temperature reactors at Springfields are satisfactory. Welded Monel metal vessels require a very high standard of welding to be satisfactory.

"Storage, Pumping and Piping of Hazardous Liquids" was discussed by S. F. Grover and B. G. Wilson. Toxic materials should not be stored or pumped unless it is absolutely necessary; it is better to feed the material to the next process to convert it into a less hazardous one. In addition to keeping the toxic vapour out of the atmosphere, the toxic liquid must be kept out of the public sewers when it has been spilt; one method is to surround the storage tank by a bund. The modern technique of welded lines reduces maintenance on joints and all lines must be designed to be self-draining or they should be back-washed.

Hot liquids should not be stored or conveyed across areas frequented by operators and overhead installations should be avoided if possible.

Flammable liquids should be stored outdoors. The vapour space in tanks containing liquids above their closed cup flash point contains an explosive mixture, and floating roof tanks or blanketing with an inert gas overcomes this. Trenches and ducts are not recommended when the vapour is heavier than air, unless fire stops are made.

It is usual to include a corrosion allowance over and above the designed thickness of a material of construction. Regular inspections should be made to ensure that the corrosion allowance has not been consumed. Vessel manhole covers should be 20 in. diam. Two manholes are better than one. Robust pipes are necessary to carry hazardous fluids. Use minimum of 2 in. diam. for connection pipes. Flanged pipes preferable to screwed fittings but welded pipe is better.



The earliest chemical industry

Alum has been manufactured by Spence for over 100 years. It is one of the oldest chemicals used by mankind; indeed there are references which go back 4,000 years. In addition to being one of the largest manufacturers of alum and aluminium sulphate for paper making and water purification Spence are also producers of catalysts for petroleum refining and organic titanium compounds for the paint, plastic and textile industries.

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AMERICAN LETTER

Increasing Scope of Fluidisation

FLUIDISED handling methods (as distinct from pneumatic conveying) have become fairly standardised both in the U.S.A. and Europe. For short distances, material of a suitable particle distribution and size is levitated in a trunking system by air diffusing through porous pads of fabric or tile—e.g., the Fuller "Air-Slide" or the Kennedy "Air-Float". Provided the material and the air are dry, the fluidised mass will flow from point to point by gravity. In some instances, fluidised transfer can also be induced by means of specially designed vibrating conveyors. For long-distance transportation, low-pressure air supplies the motive power, the material being admitted to the system and fluidised by means of specially designed pumps of the continuous screw or the batch tank-ejector type.

Continuity of discharge from silos or bins is assured by air-diffuser pads located at strategic points, sometimes assisted by mechanical vibrators or agitators. Of course, not all types of material can be handled in this way. Nevertheless, one firm, The Fluidizer Co, which specialises in high-density-low-velocity techniques, reports some 400 products as being amenable to fluidised handling, including some with moisture contents up to 15%.

Of particular interest is the increasing use of large-scale, fluidising equipment for continuous drying and reaction purposes. Many commercial units are based on extensive pilot work undertaken in diminutive 4-in. and 12-in. diameter machines. The researches by such workers as Wen, at the University of West Virginia, and by Leva have also made valuable contributions to the art.

Perhaps the first commercial fluid-bed unit was the original Esso catalytic cracker, developed in the early 1940s, which employed a moving bed of inorganic catalyst. Following this application, fluid-bed techniques were seen to have a number of specific uses in other industries and the Dorr Co. was licensed to develop its series of "Fluo-Solids" units for drying, calcination and other purposes. Later U.S. entrants to the field included the Raymond and the General American Transportation companies.

The basic components of a fluid-bed drier or reactor comprise a large cylindrical vessel separated into an upper and a lower compartment by a perforated floor, a source of low-pressure air, plus a heating unit, a solids feeding system and a dust-catching device. In operation, solids of appropriate size are fed into the upper chamber and are fluidised by air or gas passing through the perforated floor. Very rapid drying or reaction is obtained, because of the excellent heat-transfer and gas-to-solids contact offered. Furthermore, because of the high degree of turbulence induced, a uniform temperature throughout the bed is almost instantly obtained, even with high rates of cold or wet feed. This is particularly valuable when critical temperature control is necessary, as in some roasting operations. Another useful feature is the simultaneous ability to size particles of different dimensions by varying such items as air pressures or gas velocities; small particles or material of lighter density will pass out with the gas stream, while larger or heavier material will flow from the bed.

Roasting Operations

Pyrite and Pyrrhotite Roasting for SO_2 Production. The world shortage of sulphur which arose a decade ago gave a great impetus to the use of fluidised-bed roasters for producing sulphur dioxide from local sources of pyrite and pyrrhotite, to make sulphuric acid and bisulphite cooking liquors. Literally dozens of large units were installed in many countries for these purposes, especially in Canada and Africa. In some instances, the heat of reaction is partly recovered in waste-heat boilers, and the modern trend in units of this type is towards steam coils in the bed as a means of additional heat recovery and temperature control. A standard method of controlling bed temperature is to add water to the slurry feed or to the bed as required.

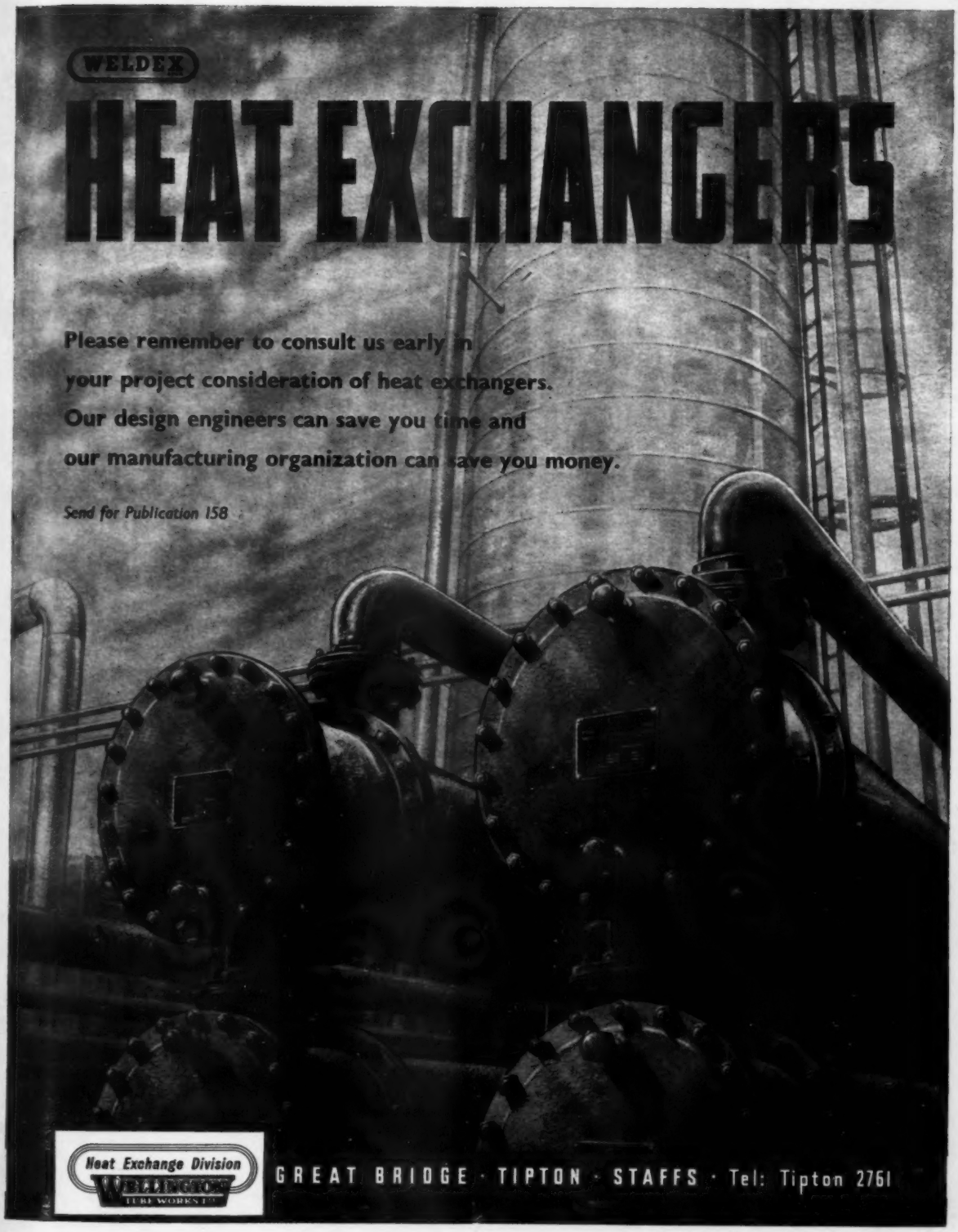
Non-ferrous Ore Treatment. Sulphate roasting of numerous non-ferrous ores has been particularly successful because of the delicate process control made possible in fluid-bed equipment. A typical case is the American-designed Japanese roaster at Kosaka, where copper-zinc flotation concentrates are mixed with spent zinc electrolyte to make a slurry containing 75% solids, which is roasted in a 20-ft-diameter reactor at 1300°F. The reaction temperature can be controlled within 10°F and roaster gases contain sufficient SO_2 to permit the production of sulphuric acid after passing through a waste-heat boiler and a two-stage cyclone. Solids recovered from the cyclone and the bed are sent to quench tanks and subsequent sulphate leaching operations.

In another ingenious process used at Bagdad, Arizona, U.S.A., carefully controlled roasting of a chalcopyrite ore (which contains oxides and sulphides of iron and copper) in a fluidised-bed reactor enables the copper to be solubilised while maintaining the iron in an insoluble condition. Subsequent leaching and electrolysis yield cathode copper and sulphuric acid; the latter is used to produce cement copper from a nearby oxide dump.

Drying, Sizing and Calcining

Fluidised-bed driers have been particularly successful, especially where particle breakdown is to be avoided, and the list of U.S. applications includes coal, limestone, salt, gilsonite, synthetic resins and organic crystals. Within the last five years, several large fluid-bed coal driers have been installed, with capacities ranging from about 70 to 800 t/h. of wet coal, the latter output being obtainable in the latest type, single, 14-ft-diameter units. The feed size ranges from 1½ in. × zero, and heat requirements may be as low as 1600 Btu/lb of water removed. Input moistures may be as high as 22%.

The drying and calcining of such materials as phosphate rock, limestone and carbon are also ideal applications. In one New England plant a 9-ft I.D. × 22½-ft high unit dries and de-dusts some 125 t/d of −5 mesh limestone. Free moisture is reduced from 3% to under 0.1%. The dried stone is then sent to a five-compartment fluidised-bed calciner, 17½ ft in diameter × 49 ft high, which produces a high-calcium quicklime containing 99.5% CaO. It is reported that the replacement of rotary kilns by the fluid-bed reactor has resulted in an increase in output from 160 to over 400 t/d, with a simultaneous decrease of 25% in space requirements. Fuel consumption by the calciner is said to be about 30 gal. of Bunker "C" oil per ton of lime. Smaller units are also successful; a 30 t/d calciner installed in Lancing, Michigan, is used to produce lime from the city's water-treatment plant sludge for re-use in the plant. Another interesting fluid-bed calciner was installed in a Kansas City sugar refinery to dry and reactivate spent carbon.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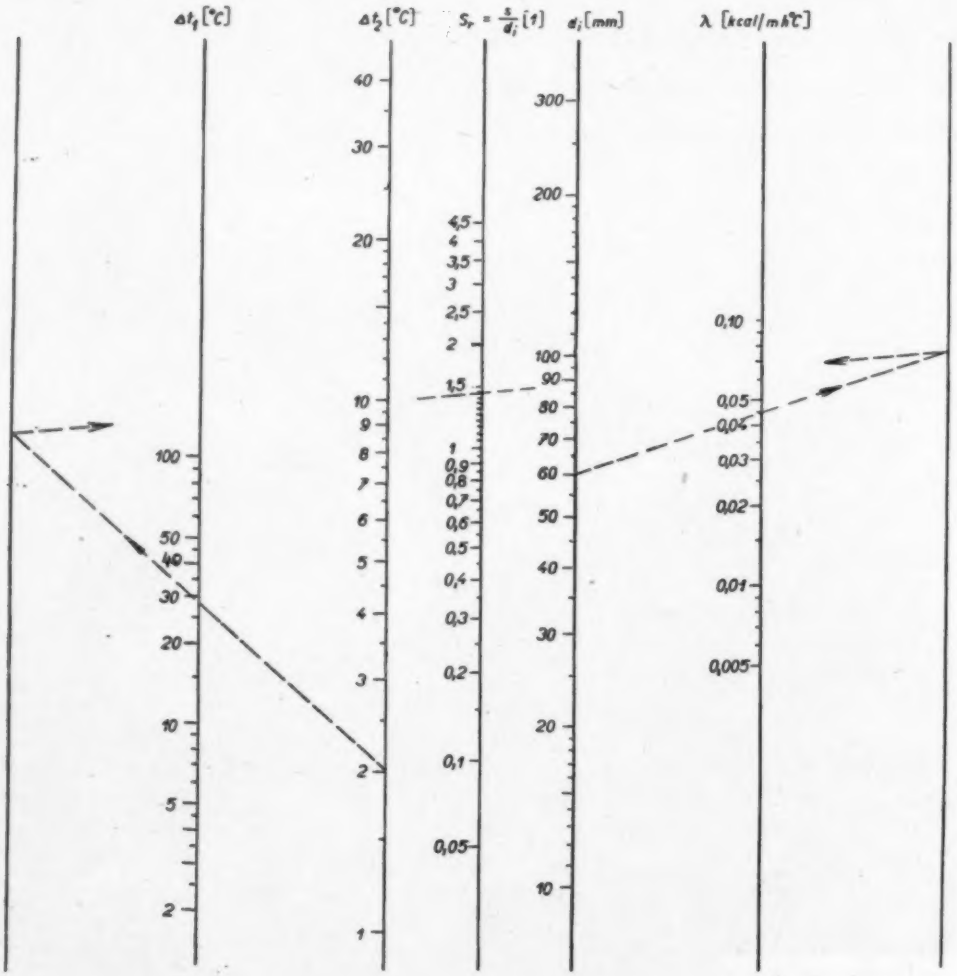
CALCULATION OF PIPE LAGGING THICKNESS TAKING DEW POINT INTO ACCOUNT

$\Delta t_1 = t_z - t_r$(°C) — t_z is the temperature of the outer lagging surface;
t_r is the temperature of the internal surface of lagging.
$\Delta t_2 = t - t_z$(°C) — t is the temperature of the surrounding air.
d_i (mm) — internal diameter of lagging.
λ (kcal/mh°C) — thermal conductivity of lagging.
α_z (kcal/m²h°C) — coefficient of heat transfer.
s = lagging thickness, mm.
$S_r = s/d_i$ (1) — reduced lagging thickness, so that $s = S_r d_i$(mm).
The nomogram is based upon $\alpha_z = 4$ kcal/m² h °C.
Example: $\Delta t_1 = 28$°C. $\Delta t_2 = 2$°C $d_i = 60$ mm $\lambda = 0.045$ kcal/m h°C

Solution: The joins of the Δt_1 and Δt_2 points and of d_i and λ are extended to cut the left and right hand reference lines respectively according to dotted lines $S_r = 1.44$, then $S = S_r d_i = 1.44 \times 60 = 86.4$ mm $\simeq 90$ mm. For identical conditions, but different α_z, for instance $\alpha_z = 8$kcal/m² h °C, the procedure is the same, but the dotted connecting line will pass the point
$\lambda \cdot 4/\alpha_z = 0.045 \times 4/8 = 0.0225$ on the λ axis. Then $S_r = 0.85$ and $S = S_r d_i = 0.85 \times 60 = 51$ mm $\simeq 60$ mm.



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AMMONIA

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PROCESS ENGINEER'S NOTEBOOK

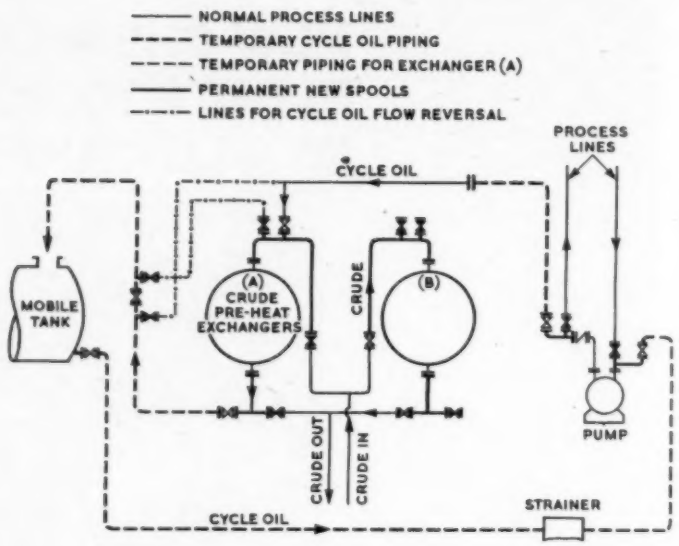
Removing Accumulated Fouling Deposits

THE FOLLOWING METHOD was used to remove accumulated heavy fouling deposits from crude-vacuum residuum heat exchangers in a refinery where the crude was preheated by exchange with various product streams before entering the furnace. It is considered that the method could be applied to other continuously-operating plants where the following conditions apply:

(1) the stacks produce serious fouling;
(2) the unit possesses two banks of heat exchangers which can be shut down alternately without shutting down the whole unit;
(3) the unit possesses two pumps for each critical service, one operating and one spare; and
(4) operation for one or two days at reduced throughput can be tolerated.

The cleaning procedure which is outlined in the drawing was carried out as follows:

(1) several spools were removed and replaced by permanent valved spools at the exchangers and at one of the vacuum residuum pumps; and
(2) temporary spools were fabricated and kept till cleaning was ready to commence. Sets of these temporary spools were provided for each exchanger.



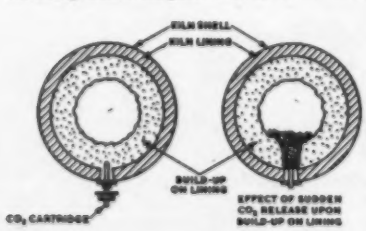
The cleaning of exchanger A is described. A similar procedure was followed for exchanger B.

Crude throughput was reduced and exchanger A isolated from the system. The various temporary spools were fitted and a mobile tank containing 2000 gal. of light cycle oil brought into the crude unit. The spare vacuum residuum pump was used to circulate cycle oil at 500 gpm through exchanger A for 8 hr with flow reversals every half an hour. The cycle oil was heated to 300° by steam on the shell side of the exchanger. When exchanger A was cleaned, the temporary spools were removed, replaced by different temporary spools and exchanger B similarly cleaned.

K.J.J.

Removing Build-up upon Kiln Linings

THE CONTROLLED VAPORISATION of carbon dioxide is made use of by the Steetley Magnesia Co. (Hartlepools) to remove build-up in their magnesia roasting kilns. Liquid CO_2 is contained in tubular cartridges of high-tensile steel which are disposed around the periphery of the kiln shell at regular intervals. Each cartridge has a fuse plug at one end and another plug with a mild-steel disc at the other end. A filament wire energised by low-tension current ignites a heating compound to produce a rapid evolution of CO_2 gas. As a result, the disc ruptures allowing the gas to escape at high velocity through posts in the plug, which is also provided with springs to anchor the cartridge.

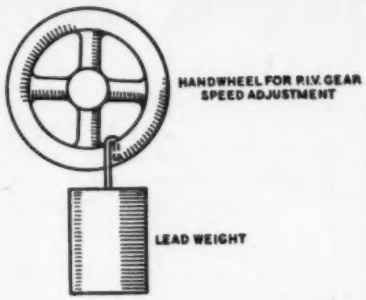


The escaping gas blasts away the build-up of magnesia upon the lining of the rotary kiln, in the manner shown in the illustration. The entire set of cartridges around the periphery will be set off at intervals in order to maintain a clean lining.

The cartridges are recovered for reuse which requires that the mild-steel disc, the sealing rings and the heating compound are replaced and the cartridge charged from cylinders. The system, known as the Cardox, has been extensively used in the mining field and it may well have many more processing applications.

Stable Feeder Control to Fluid-bed Roaster

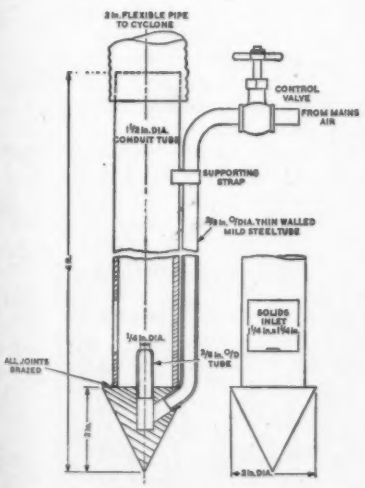
THE ILLUSTRATION SHOWS a very simple means of ensuring a steady feed of pyrites to a fluid-bed roaster used in sulphuric acid manufacture. The feeder used is of the rotary table type provided with an adjustable knife to vary the depth of the pyrites layer fed to the roaster and with a variable speed drive (P.I.V. type). The position of the adjusting handwheel of the drive tended to shift through vibration with the result that operation of the roaster was upset either through too little or too great a feed rate of pyrites. Originally to overcome the problem of variable operation arising from uncontrolled variation in speed of the table feeder, much more complex means were contemplated to ensure an even feed of the flotation pyrites used at this plant. The diagram shows the extreme simplicity of the device which was actually used. By the means



shown — the suspending of a lead weight from the handwheel—its movement through vibration is prevented and a steady speed of rotation of the feeder assured. (This notebook item was provided through the courtesy of the engineering staff at the Chemical Works at Spolana Neratovice, Czechoslovakia.)

Portable Pneumatic Elevator for Granular Solids

GRANULAR SOLIDS ARE often supplied or stored in large steel drums containing up to 300 lb. each. If this material is to be transferred to a process storage hopper, a mechanical tippler is normally used to empty the drums into the feeder of some kind of elevator which then transfers the solid to the bunker.



In an experimental plant processing coal, the top of the feed storage hopper was almost 20 ft above ground level. The problem of filling the hopper with dry −10 B.S.S. coal from drums at ground level was solved by using a pneumatic conveying system which extracted the coal directly from the drums by using an "immersion stick". The "stick" is illustrated in the diagram. A length of 1¼-in. o.d. conduit was reduced at its lower end to a sharp point (for easy immersion in solids) by brazing a solid mild-steel cone to it. An air supply tube (⅜ in. o.d.) provided with a valve ran along the outside of the conduit and entered the top of the cone. Channels drilled in the cone reversed the air flow so that it passed vertically through a nozzle formed by reducing the end of a short length of ⅜-in. o.d. tube. The air issued from the nozzle at a high velocity and the coal was dragged into the conduit through a 1¼-in.-square window cut just above the cone. The top of the "stick" was connected to a cyclone separator immediately above the storage hopper by means of flexible hose. Using compressed air source at 70 psi, the following results were obtained:

Volume of Air scf/min.	*Wt. of Coal Lifted lb./hr*
15	280
19	300
24	360
30	410
46	525 (max. air flow)

W. H. NEWTON
G. O. DAVIES

"Mousing"

THE OPERATION OF MOUSING is familiar to most plant engineers in chemical works, and consists of the scaling out and desludging of service lines and drains with a mouse, which consists of a rubber plunger with a scraping edge; the device is forced down the line with hydraulic pressure from a high-pressure fire pump.

These rubber plungers are made by several commercial firms and theoretically they can be used over and over again. Unfortunately, however, it is sometimes impossible to recover them in the appropriate sump, and their use becomes rather costly in these circumstances.

To overcome this, home-made mice have been made in the following manner. Hessian rope is wound into a ball in the manner of a ball of wool, and of the requisite diameter to make a neat fit in the drain, and is then carefully wrapped around with heavy barbed wire, the ends being finally welded together to form a close-fitting cage for the hessian rope ball.

These have proved to be excellent for cleaning and descaling purposes. They can be used over and over again when recovered, and if not recovered the cost is practically negligible compared with that of commercial models.

F. MOLYNEUX

Contributions invited

THE EDITOR invites readers to submit, for possible publication in "Process Engineer's Notebook", notes on practical devices that have been elaborated on the job for improving the operation or increasing the safety of processes, or that have been extemporised in special circumstances. The contributions preferably should be of about 250-500 words, and be illustrated with a line diagram or sketch, or a photograph. A minimum of three guineas will be paid for each contribution used. They will be published anonymously or under the contributor's name, according to his wishes.

SOME RECENT CHEMICAL ENGINEERING THESES

Equilibrium Properties of Binary Systems

by P. Snowden (Ph.D., London University)

An apparatus was developed to investigate the solid-liquid-vapour equilibrium diagrams for the two binary systems carbon dioxide-propylene and carbon dioxide-cyclopropane over a pressure range 0 to 2 atm. and temperature range 100°K to 260°K. This involved the construction of a novel type of low-temperature thermostat capable of maintaining temperatures between 290°K and 100°K to an accuracy of approximately ±0.02°K, and which was also capable of cooling steadily at a rate of approximately 0.1°K a min.

The liquid-vapour equilibria were investigated by the dew and bubble point methods and the solid-liquid equilibria by the method of thermal analysis. A limited amount of data on the density of the liquid phases was also obtained.

The liquid-vapour equilibria data were tested for thermo-dynamic consistency and were used to calculate the relative Gibbs functions, enthalpy, entropy and internal energy of the system at 2 atm. pressure and various temperatures between 200°K and 185°K.

The deviation from ideal behaviour was quite marked; in particular, the solid solubility of CO_2 in the hydrocarbon liquids was much less than expected, assuming ideal behaviour. The excess Gibbs function, enthalpy and entropy of mixing, were all positive.

Separation of the Product Gases in the Manufacture of Carbon Disulphide Direct from Hydrogen Sulphide

by K. J. Round (Ph.D., London University)

An apparatus is described which is suitable for determining the dew and bubble points of binary gas and liquid mixtures at pressures up to 30 atmospheres and over a temperature range from 50°C to −80°C.

The apparatus has been used to determine liquid-vapour equilibrium data for the system carbon disulphide-hydrogen sulphide.

Properties of the system, which showed large positive deviations from ideality, have been expressed in terms of activity coefficients over a range of temperatures from −30°C to 30°C. Equilibrium diagrams at several temperatures and pressures have been prepared and some calculations of enthalpy and excess entropy of mixing have also been made.

Data obtained in the research has been used as the basis for a discussion of a gas separation process operating at low temperatures and suggested for use in conjunction with a new process for carbon disulphide and manufacture.

Non-adiabatic Flow of Fluids Through a Porous Material (with special reference to boiling liquids)

by G. R. Newman, (D.I.C., London University)

An example of the non-adiabatic flow of a heterogeneous fluid is that of a boiling liquid through a porous material. It has the special feature of intra-pore generation of the non-wetting phase. Such flow occurs in sweat-cooling, when the coolant vaporises.

In the thesis existing knowledge of liquid/gas mixture flow is used to postulate the flow behaviour of a liquid when intra-pore ebullition occurs. It is shown that precise predictions cannot be made.

For the determination of flow characteristics it is shown that at least two intra-pore quantities must be measured—in particular the variations in the direction of flow of the liquid temperature and of the degree of saturation of the porous material. Since conventional methods of measurement cannot be applied when boiling liquids are present, a technique has been devised based on impedance comparisons; interference with the flow is avoided, since no physical contact with the porous material is made.

A suitable experimental arrangement is described. Tests were performed, using water flowing through a heated packing of glass beads, at several levels of heat-input. From measurements of the intra-pore quantities and of the variability of the mass flow rate it is suggested that at low levels of heat-input small quantities of stationary vapour are formed and that on increasing the heat-input larger quantities of mainly mobile vapour appear.

The measurements showed stationary vapour to be associated with increased variability of the mass flow rate and to impede the flow of heat to the liquid. Mobile vapour neither causes variability of the mass flow rate nor impedes the flow of heat.

It is concluded that precautions must be taken in applications of non-isothermal liquid flow to prevent the accidental formation of stationary vapour. Whenever liquid/vapour mixture flow is required, a degree of vaporisation associated with flow rate constancy should be aimed at.

It is pointed out that the impedance method for determining intra-pore quantities can also be used for finding the temperature and/or the relative quantity of liquid during the flow of liquid or mixtures of liquid/liquid, liquid/vapour or liquid/gas. The method may be adapted for measuring the temperature of the porous material.

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A Ruggles-Coles class XF directly heated dryer. It is 50 ft. long and 80 ins. diameter. A large number of similar dryers have been supplied to I.C.I. The background illustration is an interior view of a class XC steam dryer showing a single set of tubes.

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Book Reviews

Reaction Kinetics for Chemical Engineers
by Stanley M. Walas
McGraw-Hill Book Co. Inc., 1959, 338 pp., 74s.

THE main objective in the design of a chemical reactor is to determine the optimum size and shape of reactor for the manufacture of product at the required rate and the minimum cost. The design procedure involves the calculation of chemical reaction rates in conjunction with the transport processes involved. The title of this book suggests that it is restricted to the kinetic aspect of reactor design; its contents, however, extend over the whole subject of design, including scale-up and industrial reactors, and it could be more appropriately entitled "Design of Chemical Reactors". It is similar in approach and contents to an earlier volume by J. M. Smith on chemical engineering kinetics and its ancestry can be further traced to Houghen and Watson.

The first few chapters are devoted to chemical kinetics. Treatment is simple and clear with theory restricted to a minimum and emphasis placed on the practical aspects. The following chapters deal exhaustively with their respective topics: continuous stirred reactors, homogeneous flow reactors (continuous tubular and semi-continuous), uncatalysed heterogeneous reactions (absorption with chemical reaction), fluid phase reactions catalysed by solids, fixed and fluidised beds and heterogeneous catalysis. The scale-up problem is dismissed in 10 pages and the book is concluded with a chapter on industrial reactors, a short review of mathematics and an extensive list of references. The subject-matter is well illustrated with numerous worked examples and a list of problems is provided for students.

Chemical reactors have always presented a difficult design problem and, in contrast to the situation for other unit operations, resisted all attempts directed towards the rationalisation of the design procedure. This book reflects the considerable advance which has been made so far and is a welcome addition to the literature on this important topic. Whilst the design methods are presented well and augmented with many good numerical examples, the treatment is based on the considerations of kinetic and thermal aspects of chemical reactions; the effect of flow characteristics in continuous reactors is completely ignored. The concept of residence time distribution is not even introduced and the design of continuous reactors is restricted to the extreme ideal systems of plug flow and complete mixing. In the latter case, the design methods are rigorous only in the case of first-order reactions unless the effect of "segregation" can be neglected. In extenuation, it may be said that this aspect of reactor design, which is of fundamental importance, is not probably ripe as yet to be formulated into a sound design procedure. Certainly the above criticism does not preclude the book from being a useful tool in the hands of chemical engineers engaged in the design of chemical reactors. T. A. KANTYKA

Chemistry for Engineers
by E. Cartmell
Butterworths Scientific Publications, London, 1959, 172 pp., 25s.

IT is suggested by the publishers that this volume is intended as an "elementary treatment of chemistry" for students starting degrees or Higher National Certificate courses in all branches of engineering science. In fact, the chemistry contained in it is almost certainly known to an Advanced Level G.C.E. student, but he should find here many new examples of its application, presented in a very readable form. However, for the particular case of the chemical engineering student, the material, although interestingly set forth, is inadequate both as a consistent and comprehensive background and as an introduction to fundamental principles.

A large number of topics, such as metals, corrosion plastics and water treatment, are loosely ranged under two main themes: the chemistry of power production and the chemistry of materials. Some chapter headings seem to promise a fundamental discussion—e.g., "Atoms and Molecules", "Chemical Reaction"—but their contents prove to be fragmentary, possibly because of the extreme compression which is inevitable when a large field is to be covered by a small book.

This necessity for brevity and simplification may also account for a weakness in the treatment given to the chosen material. There is insufficient discrimination between elementary material which may be regarded as settled and more advanced problems and theories which still remain more open to investigation than the author manages to indicate. Nonetheless, as a volume for preliminary reading the book offers the student an attractively written and presented work at a very moderate price.

W. STRAUSS

Telemetering Systems
by P. A. Borden and W. J. Mayo-Wells
Chapman & Hall, London, 1959, 350 pp., 68s.

THIS volume, a development from the earlier "Principles and Methods of Telemetering" by Borden and Thynell, gives a broad descriptive review of methods of converting a given magnitude into a convenient electrical signal, transmitting it by wire or radio across the distance and then its reconversion into a quantitative display or control signal as may be required. Impetus in this field has recently come from rocketry research, but the subject has many down-to-earth applications of importance to the process industries.

Transducers described are capable of converting the measured magnitude whether of flow, pressure, temperature, phase or what it may be, into an electrical signal directly or by modification of electrical characteristics. In themselves, these transducers are often the solution of measurement problems particularly in high-pressure systems. The value of remote tank gauging systems or the need for telemetering in the solution of long pipeline pumping problems is obvious. But, principally, the value of this book to the chemical industry lies in its demonstration of how well developed and proven are the electrical techniques described. It comes at a time when the advantages of electrical systems for the computation demanded by more advanced control are being increasingly appreciated.

Shorter Notices

B.S. 679: 1959. Filters for Use During Welding and Similar Industrial Operations. 5s.

THE STANDARD, dealing with filters for eye protection during welding and similar operations, includes requirements for quality, classification for both density and colour, thickness and optical uniformity. Methods of test are given for permanence, resistance to heat and moisture and for flammability, together with recommendations for the grades of filter to be used for different types of welding.

B.S. 1542: 1960. Equipment for Eye, Face and Neck Protection Against Radiation Arising During Welding and Similar Operations. 5s.

IN THIS STANDARD requirements are specified for equipment to protect an operator above the shoulders against harmful radiation when engaged in welding, cutting and similar operations. The equipment is designed to use filters conforming to the requirements of B.S. 679 and giving protection against radiation of wavelength greater than 2000 Å.

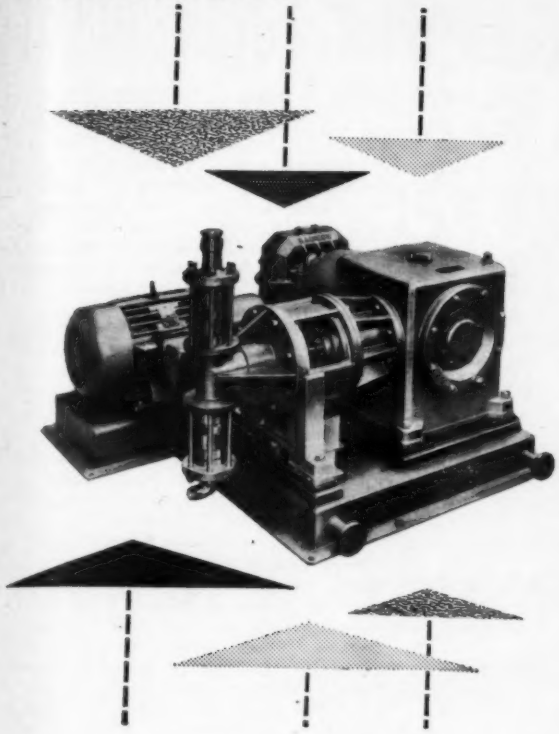
B.S. 3228: Part 2:1960. Procedures for Obtaining Properties of Steel at Elevated Temperatures. Part 2. Rupture Strength. 3s.

THIS IS ONE of a series of procedures for obtaining the data necessary to determine the properties of steel at elevated temperatures, and relates to rupture strength. This property depends on the method of manufacture of the steel, the composition, including residuals and trace elements, the heat treatment and the section size. Consequently, a number of casts have to be tested in order to determine the scatter of properties. The extent of scatter depends also on the number of samples tested and the testing technique. Tests are carried out in accordance with the requirements of B.S. 3082: "Mechanical Testing of Steel at Elevated Temperatures", Part 2: "Stress Rupture".

British Standard Glossary of Terms in Work Study. B.S. 3138: 1959, 7s. 6d. British Standards Institution, London, W.1.

In a rapidly-growing field such as work study new words have been created to avoid long explanations. Common words have been given special meanings and sometimes the same words have come to mean different things to different people according to the context, or the aspect of work study in which they are used. The purpose of this glossary is to introduce standard terms and definitions to facilitate communication and the spread of knowledge in the field of work study.

BCE 7643 for further information



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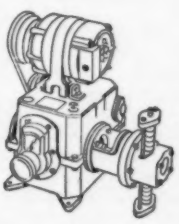
This is the metering pump we recommend for clear corrosive liquids, for alkaline suspensions, for boiler feed conditioning reagents. There are other uses, too, of course, which our highly-trained representative will explain if you ring EALing 6264 and ask him to come along to see you. In the meantime, jot down these very brief points about this new Metricon pump, type 'W'. It is a reciprocating pump with a fixed length of stroke of 2¼ inches. A variable speed gear can be supplied so that the pump stroking speed can be varied manually, electrically, or pneumatically. Flame-proof or weather-proof motors as well as screen-protected machines can be supplied. (This pump is an addition to our already extensive range of metering pumps). Asking our representative to call, means not the slightest obligation, of course.

Metering Pumps Limited

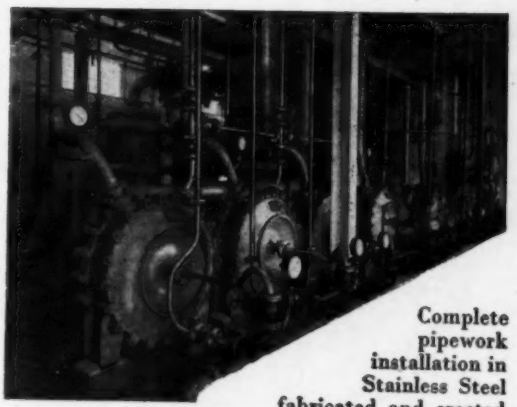


21 The Mall, Ealing, London, W.5.
Telephone : EALing 6264 (PBX)

BCE 7644 for further information

Stainless Steel . . .

tanks, coils and pipework by *Jenkinsons*



Complete pipework installation in Stainless Steel fabricated and erected on site by JENKINSONS.

Also fabricated and erected on site by JENKINSONS, Stainless Steel ducting 9 ins and 18 ins dia. with special smooth finish both internally, to minimise friction losses, and externally, to improve corrosion resistance.

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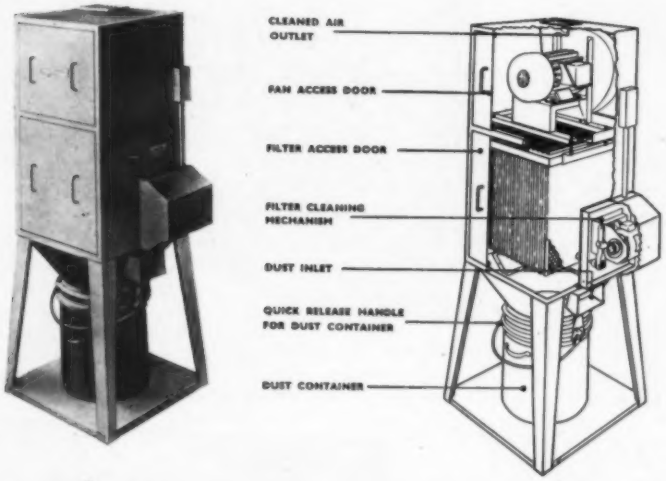
PLANT EQUIPMENT NEWS

Dust Collector

A new dust collector—the Unimaster—is now available from Dallow Lambert & Co. Ltd. The collector embodies many new improvements and is the successor to the company's Dustmaster collector which has been applied to thousands of process dust problems in many industries throughout the world. The Unimaster is a completely self-contained collector incorporating the very latest developments in dust control technique and embodying the following features:



(1) New standard in compactness of design, giving greater filtration area per floor space required.
(2) Built-in fan of more efficient design with increased fan capacity and duties. (Handles cleaned air only, discharged upwards to avoid draughts. Acoustic duct available as standard accessory when noise suppression is of special importance.)
(3) Improved fabric filter element of patent design, with a variety of fabric materials available to suit the dust being handled.
(4) Extremely efficient motorised "air cushion" filter cleaner (British and foreign patents pending) with push-button control for fan and filter-cleaning mechanism. Completely automatic cleaning available as an extra.
(5) Simplified quick-release sealing gear for easy removal of dust container.
(6) Alternative sizes of dust containers, quickly and easily emptied.
(7) Flush-fitting, easy-access inspection doors to fan, motor and filter.
(8) Dust inlet connection openings available on three sides of collector with one inlet spigot supplied as standard.

In the Unimaster almost every type of dust produced by the widest possible range of machines and processes can, it is said, be effectively controlled. This flexibility of application is made possible by the fact that it can be supplied with a variation of fans and motors, filters and dust containers. Applications requiring a large air volume but producing little dust can be dealt with just as effectively as those in which the air requirement is small and the dust load heavy. Light, bulky dusts can be handled as easily as heavy, concentrated dusts.

The new collector is initially available in the 70 series (70 sq. ft of filter cloth area), fan capacity range 0 cfm at 6.2 in. w.g. to 765 cfm at 3.3 in. w.g. Full details from **Dallow Lambert & Co. Ltd., Thurmaston, Leicester.**

BCE 7692 for further information

Industrial Incinerator

Demonstrated recently for the first time in Britain was the Hoskinson industrial incinerator which will destroy, without smoke or smell, rubber, plastics, leather-cuttings, paint in tins, etc., and at the same time provide valuable heat which can be used for auxiliary space heating if some other form of heating is already installed. The unit includes an automatic oil burner which can take the place of the major heating unit. The capital cost to achieve the same heat is said to be less than 50% that of conventional heating and the unit is said to be easy to install. It can be sited either outside or inside a building with equal effectiveness. Although patented in America and licensed to the Boston Marine General Engineering Co. Ltd. for the U.K., Europe and other overseas territories, the British manufacturing design team have been able to incorporate so many additional features and improvements in efficiency that the American originators are reported to be placing orders for the British version at the rate of 600-1000 a year. **Boston Marine & General Engineering Co. Ltd., Heath Town Works, Deans Road, Wolverhampton.**

BCE 7693 for further information

Variable-output Metering Pump

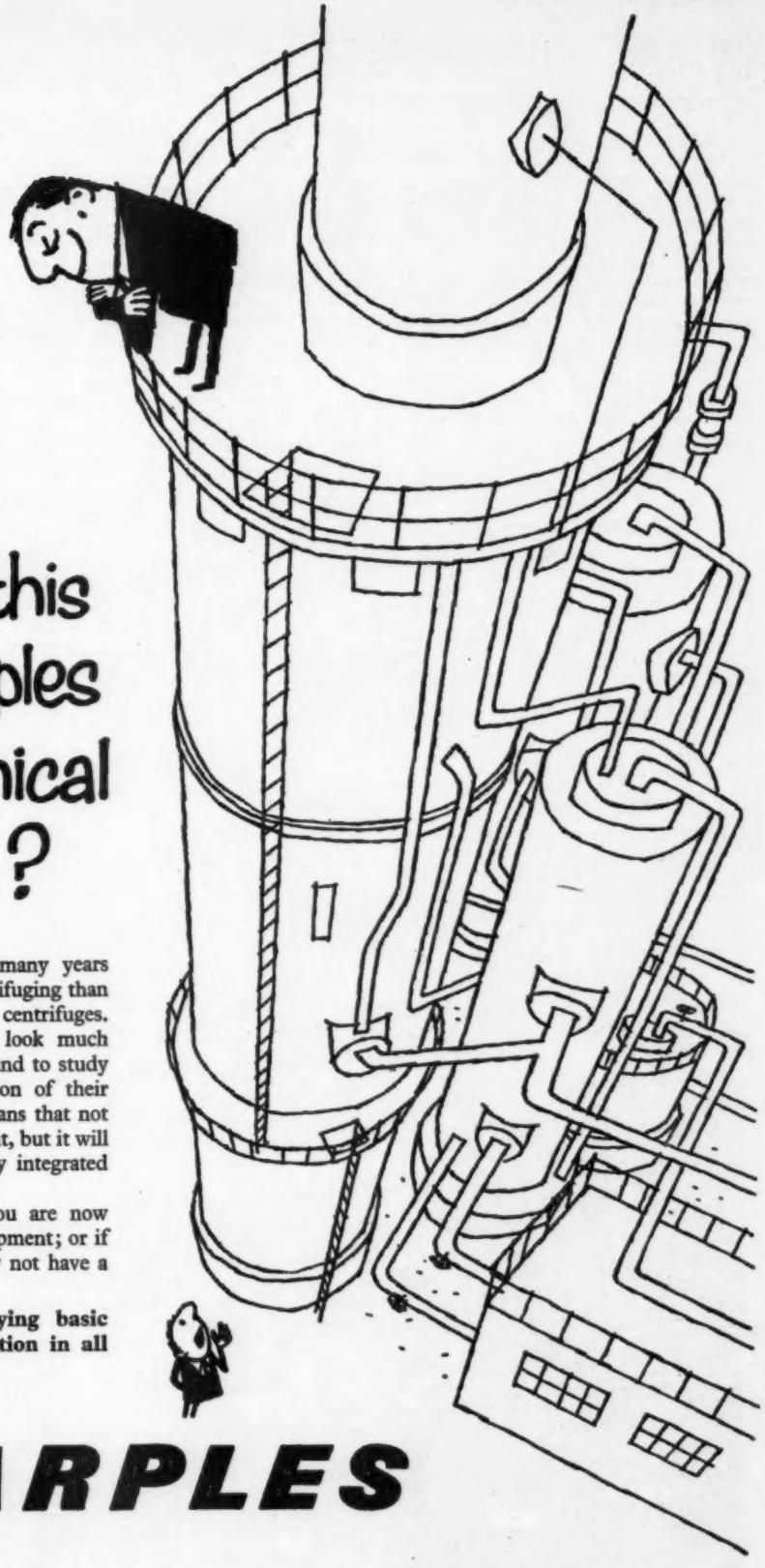
The Metrivar type K is a small-capacity variable-output pump driven by a totally-enclosed vertical spindle 50 c/s motor. A reduction gear is incorporated in the gearbox and any of three pump speeds can be specified. Capacities (on 50 c/s) range from 0.35-3.6 gal./hr at maximum working pressures ranging from 50-500 psi, depending on the type of pump head and stroke speed. The length of stroke can be varied from zero to maximum ($\frac{1}{2}$ in.) while the pump is working or at rest. Pump heads are available in ebonite and glass, polythene and glass and in stainless steel. The pump ram is guided and supported in the gearbox fixing and does not depend upon any part of the pump head for its alignment. It is, therefore, possible to use such materials as 18/8 stainless steel for the ram and all parts of the pump head. Ebonite-headed pumps are fitted with mushroom-shaped synthetic rubber valves. Polythene heads have glass ball valves; pumps with stainless-steel heads are fitted with flat valves with close tolerance valve lift. All the pump heads have non-adjustable U-rings, generally of synthetic or natural rubber, except the polythene head, which has a polythene non-adjustable gland. Connectors suitable for $\frac{1}{4}$-in. bore polythene tubing are fitted to ebonite and polythene pump heads. Stainless-steel heads are fitted with connectors which accept any metal tubing of $\frac{1}{4}$ in. outside diameter. Hose connectors can be fitted as an alternative. **Metering Pumps Ltd., 21 The Mall, Ealing, W.5.**

BCE 7694 for further information

Transistorised Computer

Electronic Associates Ltd. demonstrated recently for the first time in this country their PACE (Precision Analogue Computing Equipment) TR-10, a small, entirely transistorised analogue computer which has the dimensions of a suitcase. The computing equipment is said to be accurate to 0.1% and to be capable of performing mathematical operations required in the solution of 95% of routine engineering problems. Besides its linear operational elements (which can carry out addition, integration and multiplication by a constant), it possesses a large range of non-linear elements including quarter square multipliers, function generators,

BCE 7645 for further information



Hi! What's this about Sharples being Chemical Engineers ?

IT'S A FACT. Sharples have for many years realised that there was more in centrifuging than just building a complete range of centrifuges. Their policy has always been to look much further than the centrifuging step, and to study the process as a whole. Application of their chemical engineering knowledge means that not only will the separational step be right, but it will be a unit operation that is correctly integrated with the process.

If you have a process which you are now flowsheeting; or a pilot plant development; or if you are actually in production; why not have a word with Sharples.

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PLANT EQUIPMENT NEWS

relay comparators, etc. These elements can be directly plugged in to a chassis, where they can be easily replaced by different units should the need arise. The standard basic TR-10 is capable of solving up to two second-order differential equations, plus associated linear algebraic computations. For handling more complex problems, there are the standard linear expanded and non-linear expanded models. Physical description of the unit is width 16 in.; height 24 in.; depth 15 in.; weight 93 lb. (fully expanded), power source 115 V, 60 c/s; and power requirement under 50 W (fully expanded). **Electronic Associates Ltd., Burgess Hill, Sussex.**

BCE 7695 for further information

Vacuum Gauge

For the first time a McLeod gauge has been made of very small proportions covering a range of pressures hitherto not possible. This instrument has been designed to meet the increasing demand for a general-purpose vacuum gauge giving accurate and rapid pressure readings in all situations calling for a robustly constructed McLeod gauge. It ensures trouble-free operation under the most exacting conditions. The standard model covers the range from 150 mm to 1 μ. This is achieved by the simple operation of depressing a lever which gives accurate readings simultaneously on two scales, one reading from 2 mm to 150, and the other 1 μ to 2000 μ. Unlike most McLeod gauges, the reading capillary tubes are completely separate and easily detachable from the main body by means of the knurled sealing gland. Also, due to the reproducible accuracy between each gauge, replacement scales, glasses or bodies may be made without any calibration and the volume of mercury required for these gauges is not critical. As is common in any type of McLeod gauge where mercury is in contact with glass-work, the surface eventually becomes discoloured and the deposits on the capillary tubes may lead to false readings. The glass-work is easily removed by means of the demountable "O"-ring joints, cleaned in the normal way and replaced again in a very short time. Where necessary, the whole mercury tank can be dismantled by means of the four clamping screws and the complete mechanism exposed for this operation. It is necessary to remove the mercury from the gauge before dismantling the tank as described above. Further details are available from the manufacturers, **Genevac Ltd., Pioneer Mills, Radcliffe, Lancs.**

BCE 7696 for further information

Improvement in Rust-preventing Coating

Introduction of a new anti-settlement agent into an anti-rust cold galvaniser means that practically no stirring is needed before the coating is applied. Tests have been carried out continuously for nine months by the manufacturers. Tins containing the new agent have now been standing for over 75 days, and there has been no appreciable settlement. The zinc is unaffected by the new agent, and the product, known as Rust-Anode, dries even harder than before. It provides a metal coat of pure zinc, strongly adherent and rustproof. It can be applied under paint for additional protection. The conductivity of the deposit when dry is said to be almost equal to that of pure zinc. It is non-inflammable and will withstand temperatures up to 400°F. **C. & P. Development Co. (London) Ltd., Wiggie Works, Redhill, Surrey.**

BCE 7697 for further information

Thermal Insulation

A recent introduction in the Newalls' range of products is Newtherm calcium silicate insulation. This material, which is light in weight and said to have exceptional strength, combines high thermal efficiency with good moisture resistance. It is said to be finding extensive application already in the oil and chemical industries. **Newalls Insulation Co. Ltd., Washington Co. Durham.**

BCE 7698 for further information

Flame Photometer

Continuous monitoring of sodium concentrations is possible with the new EEL recording flame photometer, produced by Evans Electroselenium Ltd. The instrument is completely self-contained, operating from a town or bottled gas supply, and an air compressor with a filter on the inlet side is fitted internally. High sensitivity is provided: full-scale deflection can be obtained on as little as 0.01 ppm sodium. Three ranges of sensitivity, together with a fine adjustment, permits full-scale settings on any desired strength of standard up to approximately 10 ppm sodium. Light falls on to a low-noise, nine-stage photo-multiplier, the output from which is fed, via a suitable amplifier, to a moving-coil pen recorder.

A fully stabilised electronic circuit compensates for voltage fluctuations. A signal light is fitted to give a high-level warning. **Evans Electroselenium Ltd., St. Andrews Works, Colchester Road, Halstead, Essex.**

BCE 7699 for further information

Centrifugal Pumps

A major advance in meeting centrifugal pump requirements is claimed for the Sultan range now being produced by Pegson Ltd. The range, comprising 42 units, is said to meet the need for a complete range giving maximum duty coverage within the permitted design limits, using a minimum number of parts and maintaining high efficiencies—characteristics which could not be achieved collectively when building up pump ranges from one or two initial sizes. The Pegson-Sultan pump is a vertically split, end-suction, single-stage centrifugal pump. It is being produced in sizes from 1½ to 12 in. suction branch diameter, with capacities from 20 to 3500 gal./min. A notable feature is the low NPSH characteristic. Basically, there are six sets of constant hydraulic shapes around which the pumps are designed. Each set of shapes produces a uniform performance pattern so that a 12-in. pump, for example, is a pure geometric enlargement of any other model in the same hydraulic group. By keeping the suction eye constant for all pumps of the same suction branch diameter, it has been possible to reduce the number of parts and increase interchangeability; e.g., although there are six 4-in. pumps in the range, one size of wear ring is common to them all. Overall efficiency of the range is also said to be higher than has been achieved before: it is possible, for

WELDED
PRESSURE VESSELS
in STAINLESS STEEL, MONEL, TITANIUM, HEAVY ALUMINIUM AND MILD STEEL

THE SIGN OF GOOD WELDING

Vacuum chamber designed for high atmospheres—⅜" mild steel plate—with flanged ports and hinged doors.

Welded fabrication and fusion-welded pressure vessels to the requirements of Lloyd's Class 1, A.S.M.E., A.O.T.C. codes and similar specification.

Welding techniques and inspection controls equal to all requirements; modern progress and planning methods to quicken delivery; capacity and full research facilities for a variety of work; all these essentials are co-ordinated by Jenkins of Rotherham to provide a production potential second to none for the fabrication of welded pressure vessels.

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ROBERT JENKINS & CO. LIMITED, ROTHERHAM

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PLANT EQUIPMENT NEWS

example, to select any pump from the range and, with a full-diameter impeller, it is always operating within 6% of peak efficiency and, with a minimum-diameter impeller, within 9%. A stable head/quantity characteristic is also a feature of these pumps, enabling them to be used satisfactorily in parallel or on booster applications. Different seals and materials are available for handling most types of liquid. The pumps are designed for working pressures of up to 200 psi. **Pegson Ltd., Coalville, Leics.**

BCE 7700 for further information

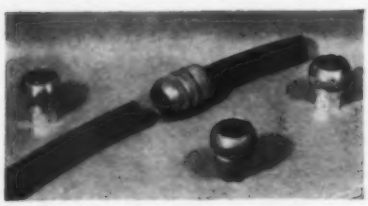
Multi-scanning Equipment

Production has been started by West Instrument Ltd. of multi-point scanning equipment for monitoring temperatures at up to 12 points in succession on an installation. The temperature indication consists of a moving-coil millivolt meter with a 5-in. scale, and sensing is by means of thermocouple or resistance bulb arrangement, according to the temperature involved; thermocouple sensing is generally effective above 200°C and a resistance bulb is used below that temperature. The instrument can be arranged for two types of action. A single, maximum temperature can be pre-set on the scale and, if the temperature at any of the scanned points reaches this, scanning stops and an alarm or trip action to shut down the machinery comes into action. On the second arrangement two temperatures can be set on the scale. If the temperatures scanned reach the lower point, a relay is operated, and this provides the necessary contact for an alarm; then, if the temperature reaches the second point, a trip action is brought into operation. There is provision for manual operation of the scanning cycle and also visual indication of the temperature indicated at any given moment. The resistance bulb instrument is connected direct to mains supply without additional transformers, the mains being rectified and stabilised to give a d.c. source within the instrument. **West Instrument Ltd., Brighton, Sussex.**

BCE 7701 for further information

Hand-tightened Hose Fittings

A new range of connectors and other fittings has been introduced which can be tightened by hand on to ends of hose and applied for such purposes as constructing a compressed-air system. The method employed eliminates the need for fittings permanently attached to the end of the hose. If a free-end fitting is attached to, say, a pneumatic tool and compressor, or any other equipment, no fittings are required on the hose. The free, unprepared end of the hose is merely pressed into the fitting and a leakproof joint effected by screwing tight by hand. Enclosed in the fitting is a stainless-steel spring that closes down and grips the hose over the whole of its surface when the locking nut is twisted. Dismantling of the system is equally simple and the fittings can be re-used. These fittings are made in polythene, nylon, brass and other metals for many sizes and wall thicknesses of hose. They cover a variety of uses in the movement of water and other liquids, compressed air and gases and are available for working pressures up to 250 psi, temperatures up to 120°C. **Hozelock Ltd., Haddenham, Bucks.**



BCE 7702 for further information

Oil-fired Boiler

A new oil-fired hot-water boiler for the high-pressure, hot-water heating of factories and large buildings is now being produced by Edwin Danks & Co. Known as the Symmetriflo, its main feature is a number of concentrically-arranged gas and water passes, which ensures high thermal efficiency as well as minimising operating stresses in the boiler by its symmetrical arrangement. This boiler is fitted with an Oldbury Air Spin oil burner, an air-turbine-driven rotary cup burner of extremely simple design in which perfect atomisation is said to be achieved at relatively low temperatures, with a reduction in heating costs. The burner is fitted with forced draught to provide sufficient air to create the turbulent mixing necessary to achieve complete combustion, with low excess air and an absence of carbon deposits. **Edwin Danks & Co. (Oldbury) Ltd., 209 Euston Road, London, N.W.1.**

BCE 7703 for further information

Butterfly Valves

A comprehensive range of Mason Neilan butterfly-type control valves are now being marketed by the Crosby Valve & Engineering Co. These are available in steel or cast iron as standard materials, as wafer types for mounting directly between pipe flanges, in standard sizes of from 2-24 in. These valves are normally supplied with air-operated diaphragm-type actuators for use with all types of pneumatic controls, but can also be supplied for lever, handwheel, chainwheel or electric motor operation. Two basic types are available—light or heavy duty—according to the pressure drop across the valve and other service conditions. Among other features, these valves are readily changeable on site from air to open, or air to close, and from 60-90 degree opening. The linkage is arranged so that the maxium possible mechanical advantage is achieved when the torque developed on the shaft by the flowing medium is at its greatest. The crank is located on the shaft

by a simple shakeproof and foolproof key. On the heavy-duty-type valves, the stuffing box is readily accessible, and exceptionally heavy studs and bolts are employed. Totally-enclosed, outboard, flexible-type roller bearings are used on all sizes. The vane is pinned to the shaft in a manner giving minimum reduction on shaft area and minimising any possible expansion effects. **Crosby Valve & Engineering Co. Ltd., Crosby Works, Ealing Road, Alperton, Wembley, Middx.**

BCE 7704 for further information

Safety Blow Gun

Working surfaces and parts can be cleared of chips, dust and waste cuttings with a new type of safety blow gun. Particles are whirled down and away by an exclusive cyclonic action, the operator being behind a conical shield of high-velocity air that is said to stop flyback. Thus the protection is part of the tool itself. Fitted with a pistol grip for easy handling, the gun operates at from 30 to 100 psi, but is pressure tested to 150 psi.

It has a rugged one-piece cast housing normally with ¼-in. male B.S.P. fitting. **John Trelawny Ltd., Queensway Trading Estate, Leamington Spa, Warwickshire.**

BCE 7705 for further information

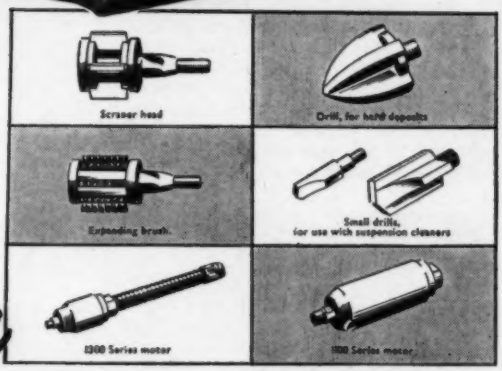
Pipe-sealing by P.T.F.E. Tape

For sealing screwed pipe joints P.T.F.E. is now being supplied in the form of tape under the trade-name Thredseal. The manufacturers state that it has been proved in use in their own works and in the field. The tape, being made of P.T.F.E., is resistant to corrosive chemicals, caustic, hydraulic fuels and aromatic fuels. It is supplied in spools loaded with 480 in. of tape of ¼-in. width. In use, a sufficient length of tape is cut off to wrap round a

There's a *Lagonda* way to clean any tube

Lagonda tube cleaners are designed to remove all types of deposits from all types of tubes. The scraper head will clear tubes as small as ½" and upwards . . . drills from ⅞" up will break down the toughest deposit. Expanding brushes, and sectional brushes will leave tubes from ¾" up as clean as new. And for even smaller tubes, there is a wide assortment of drills and brushes.

The illustration (right) is only a partial listing of Lagonda equipment, but enough to indicate that the scope of the Lagonda range covers just about any tube you may need cleaned. If you have a tough tube cleaning job, write for the Lagonda Catalogue No. Y-48.



Lagonda **TUBE CLEANERS** made by **Consolidated Pneumatic**

CONSOLIDATED PNEUMATIC TOOL COMPANY LIMITED · DAWES ROAD · LONDON · S.W.6

CP/181

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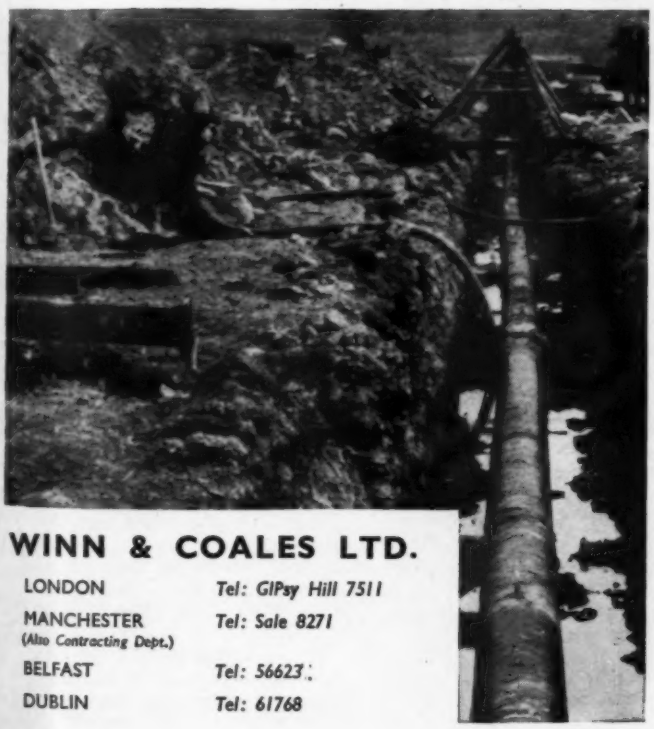

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gives complete and permanent *protection* . . .

- ***above or below ground . . . under water . . . in sub-zero or tropical climes . . . in moisture- or acid-laden atmospheres . . . anywhere . . . everywhere . . .***
- ***alike to new metals and those already partially corroded***
- ***at low initial cost***
- ***. . . and is easily cold-applied throughout a wide temperature range in factory, store or under the most unfavourable on-site conditions***

DENSO—ANTI-CORROSIVE PRODUCTS

BCE 7648 for further information

PLANT EQUIPMENT NEWS

thread, allowing for an overlap of approximately ¼ in., and the thread is screwed home. The tape is pulled taut so that it grips and sinks into the thread. Thredseal can be used on virtually any material in which threaded connections are formed. It is efficient even on imperfectly formed threads. Since P.T.F.E. is self-lubricating, the tape eliminates galling and seizing, and connections can be drawn up to a greater degree of tightness than with conventional sealing substances, yet joints can be easily broken down after long periods of time. Good seals are obtained at pressures of many thousands of psi, and temperatures of −200°F to

+500°F. A standard reel is sufficient for 120 joints on a 1-in.-bore pipe. This represents a cost of slightly less than 1½d. per joint. **Crane Packing Ltd., Slough, Bucks.**

BCE 7706 for further information

Aluminium-clad Steel

Aluminium-clad steel strip manufactured in Germany by Wickeder-Eisen-u-Stahlwerk G.m.b.H. is now being marketed in the United Kingdom under the name of Feran. This material is said to have the advantages of being cheaper than pure aluminium and at the same time having the added strength of the steel core. Among the advantages offered with T.A.L. GMC series air and electrical manifolds. The balanced spool principle, without moving O-rings or elastic seals, is said to enable the valves to operate on a very low amperage—less than 0.5 A. inrush on 230 V, 50 c/s. They can be operated by miniature hermetric and plug-in relays. The valves are provided with dual exhaust ports, which permit the throttling of exhaust for speed control in either direction of piston movement. By plugging the unused ports, the 1SGA4 can be used as a normally-open or normally-closed two-way or three-way valve. The unique solenoid capsule construction is said to permit rapid valve disassembly without loose parts. The valves are sub-plate mounted and there are two porting arrangements to suit any design requirement. **T.A.L. Numatics Ltd., Leighton Buzzard, Beds.**

BCE 7707 for further information

O.C.C.A. Exhibition

Items of interest to our readers exhibited at the O.C.C.A. Exhibition are listed below.

Sub-sieve Sizer

An established sizing apparatus originally designed for investigations into the particle size of powdered insecticides was refined for average particle size measurement (in the 0.2 to 50 micron range). Now the instrument is even more convenient to use due to the addition of a calibrator. The instrument is based on the principle that particles in the path of a regulated air flow will affect that air flow in relationship to their size. The instrument resolves the results into a series of curves which can be read directly from the copyrighted calculator chart as average particle size in micron units. Such variables as the shape of the bed, apparent volume, percentage of voids are removed or compensated for by uniformly packing a fixed weight of the sample in a precision-bore tube on the instrument. In operation, a uniformly regulated flow of dry air passes through the sample and is measured by means of a double-range flow meter. The average particle size is then read directly from the series of curves as indicated by the fluid level. The operator need only set the pointer at the liquid level of the manometer and read the average particle size directly from the curve on the calculator chart. The instru-

ment measures approximately 29 in. high, 16 in. wide and 9 in. deep. It is supplied with air pump; air pressure regulator; double-range flow meter; calculator chart; precision-bore sample tube; two porous plugs, plug manipulator; plastic funnel; sample tube support; drying agent; paper discs; and directions for use. For 115 volt a.c., 50 to 60 c/s only. **Kek Ltd., Palmerston Street, Manchester, 12.**

BCE 7708 for further information

Milling Control Gauge

A new double-channel type of fineness-of-grind gauge is designed for control of milling operations, particularly in paint

making. It consists of a hardened and ground steel plate with two channels cut in the upper surface. The depth of these channels, which may be 0.002 in., 0.004 in., 50 or 100 microns, is calibrated on the gauge. The instrument is supplied with hardened and ground doctor blade complete in wooden case. In use, a blob of paint is dropped into one of the channels at the deep end and drawn over the full length by means of the scraper blade. After the draw-down, the film is viewed at grazing incidence and the point noted at which the pigment particles merge into the film. This is done immediately after draw-down, since evaporation of solvent or shrinkage of the film might alter the results. The two channels are provided so that comparisons may be made with a control sample. **Research Equipment (London) Ltd., Wellington Road, Hampton Hill, Middx.**

BCE 7709 for further information

Motor Speed Control

To improve the flexibility of their ball mills for experimental use, Pascall have added a motor speed control unit providing speeds from 0-450 rpm on the driven roll. It may be supplied with a No. 2 laboratory ball mill arranged with a pair of 2½-in. diameter by 13 in. long hard rubber rolls bonded on steel shafts. The rolls consist of a driven roll and an idler roll which can be placed in any of three positions to accommodate ceramic or steel containers from 4½ in. to 9 in. outside diameter and up to 13 in. overall length. With a speed control unit fitted, the speed of the driving roll can be varied simply by turning a dial whilst the mill is operating. The same motor speed control unit can be used with the No. 8 model, designed to take nominal 1-gal. pots and other sizes of container up to 9 in. diameter. The mill is arranged with one driven roll and one idler roll which can be placed in three different positions to suit various sizes of pots; e.g., five 1-pint or four 2-pint or three ½-gal. or two 1-gal. Driving arrangements give three alternative speeds of 132, 190 or 277 rpm. **The Pascall Engineering Co. Ltd., Gatwick Road, Crawley, Sussex.**

BCE 7710 for further information

Laboratory-size Mixing Machine

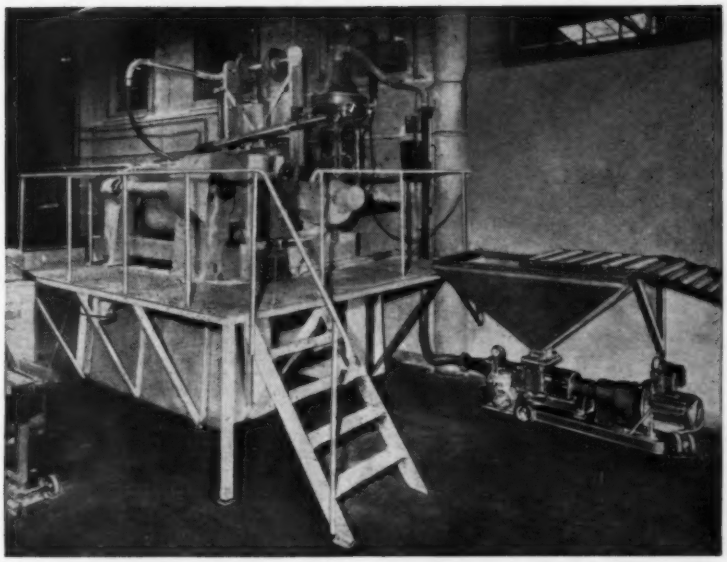
A laboratory mixer has been announced, designed especially for research chemists. It can be supplied in either 1 pint or 1 quart sizes; all contact parts are of stainless steel. The mixer can be completely dismantled for cleaning by unskilled labour in a matter of min. Models with steam- or electrically-heated jackets are available and machines arranged for full vacuum operation can be supplied. Infinitely variable speed control units can also be incorporated in the specification of these models and delivery of the whole range is generally good. **Winkworth Machinery Ltd., 65 High Street, Staines, Middx.**

BCE 7711 for further information

Grinding Mills

The smallest machine in the range of Kek pin disc grinders has been modified by introducing a Kopp variator. This

Have you thought of pumping powder on short transfer duty?



At the pharmaceutical factory of Evans Medical Supplies Limited, this P12 Mono Powder Pump is used for pumping Kaolin to their production plant.

Buckets are outdated for transferring fluid but have you considered the sack as similarly outmoded for feeding process plants.

Over many years the Powder Division of Mono Pumps Limited has obtained a mass of valuable information on the behaviour of piped powder and the Mono Powder Pump is a fully developed unit for pumping powder through pipelines.

A service is available to offer advice on the use of the Mono Powder Pumping System whether it be for small or large schemes.

✻ ***Write for leaflet DM2 to give you an initial introduction to the System.***

Powder Pumping Division

MONO PUMPS LIMITED · MONO HOUSE · SEKFORDE STREET · LONDON E.C.1

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MONO

Powder Pumping System

MP303/L1260I

model is designed for laboratory and pilot-plant use in testing small batches of new products. Overall dimensions are 23¼ in. × 15¼ × 15½ in., and total weight 160 lb. The fineness of the grind is adjusted by changing the pin discs. There are no screens and the machine is completely vibrationless when running. The B series of mills made by this firm have been changed by the use of a revolutionary type of belt drive greatly improving their performance. Compared with the corresponding gear-driven mills, the new models give at least 20% increase in output/horsepower, are simpler and cheaper to maintain, transmit no heat from the driving unit to the grinding discs, and give a product of smaller particle size when required. The range of output of these machines is from 200 to 2000 lb/hr. They can be fitted with either "involute" or "open-all-round" delivery rings to suit the nature of the material being milled. **Kek Ltd., Palmerston Street, Manchester, 12.**

BCE 7712 for further information

Three-stage Homogeniser

A wide range of materials has already been treated by the "Jet-Mogenizer"—a three-stage homogeniser using the forces of impact, attrition, turbulence and ultrasonic cavitation for dispersion, stabilisation, emulsification and blending processes. It is based on continuous recycling of material achieved by throwing out of register the spline pattern converting a constant rhythmic flow into a sustained eddying of pressure impulses. This sets up violent turbulence within the fluid mass. As it reaches the periphery of the rotor, this transfer of momentum is accelerated and utilises the kinetic energy of the fluids under pressure to transmit additional turbulence and interparticle attrition to the dispersed particles. High-velocity impingement on a sonic blade at a peripheral velocity of 4500 fpm generates cavitational effects within the fluid mass at ultrasonic frequencies exceeding 20,000 c/s, producing dispersion, stabilisation, emulsification or blending. The "Jet-Mogenizer" is available in four sizes with production ranges from 100 to 500 gph. **William Boulton Ltd., Providence Engineering Works, Burslem, Stoke-on-Trent, Staffs.**

BCE 7713 for further information

A.S.E.E. Exhibition

The Ninth Electrical Engineers' Exhibition held during April was principally devoted to industrial and domestic exhibits, even although the main theme this year was marine electrics. Items of particular interest to our readers are detailed below.

A/D-D/A Converters

Armstrong Whitworth Aircraft showed for the first time their digital-to-analogue and analogue-to-digital converters which they are confident will advance significantly the technique of complex computing and high inform-capacity conversion, as used in advanced telemetry systems, pure automation, etc. The converters are fully transistorised for compactness, and besides being among the fastest converters available (they are capable of carrying out more than 50,000 conversions a second), they are probably the smallest too for such a task. The A/D converter accepts an analogue input voltage and produces a digitally coded output representing the magnitude of the input voltage. The D/A converter accepts an eight-digit binary number in parallel form and provides a corresponding analogue voltage output. This company also showed a 20-gal. version from their range of type 101 flowmeters and their diminutive miniflowmeter which, it is stated, can measure the smallest movement in any conductive fluid, and is said to be particularly suitable for research and measurement of very small scale flows. Automatic temperature control units working on the ordinary thermostat principle, but with a working range and very high degree of accuracy enabling them to be used on anything from a test tube to a blast furnace, were also exhibited by the company. **Sir W. G. Armstrong Whitworth Aircraft Ltd., Baginton, near Coventry, Warwickshire.**

BCE 7714 for further information

Logical Elements

English Electric Ltd. introduced magnetic logical elements which are in the form of mechanically coded standard packages, providing bricks from which any control scheme may be built up. The element is presented in the form of a plug-in unit consisting of a nylon frame moulded to form a handle at one end and having a 32-way plug and socket connection at the other. Two printed component boards, one for input circuit components and the other for the magnetic circuit components, are fixed into this frame and electrical connections are taken to the plug. Each assembly is a complete logical element. Electric speed motor control units with variable speeds ranging from ¼ to 1 hp were also exhibited by this company. The d.c. range of variable speed drives is from 1 hp to 100 hp. Both the a.c. and d.c. regulation is within 4% of top speed, while the a.c. units have a speed range of 30 to 1 and the d.c. 20 to 1. **English Electric Ltd., Queens House, Kingsway, London, W.C.2.**

BCE 7715 for further information

Switchboard Instruments

Crompton Parkinson introduced a new range of industrial switchboard instruments for use as ammeters, voltmeters, watt meters, power factor indicators, rotary synchroscope indicators, frequency indicators and speed indicators, the dials of which have been specially designed for easier reading. The new dials have been brought forward so that they lie in the same plane as the front of the bezel. This ensures that the scale markings and pointer receive maximum possible illumination and that all shadows on the dial have been eliminated. It also enables the indications to be read over a very wide angle. The slightly projecting moulded glass cover is specially contoured to avoid striations of light on the dial face, and the cardinal points on the scale as well as the figures are bolder than usual. The result is an instrument with indications that are particularly easy to read even under unfavourable conditions of siting and lighting. **Crompton Parkinson Ltd., Crompton House, Aldwych, London, W.C.2.**

BCE 7716 for further information

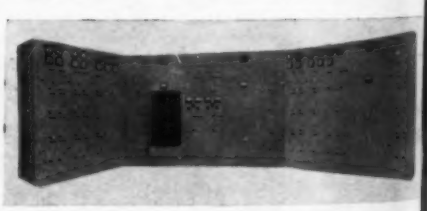
Level Controller

A resistance-operated level control designed to control the level of flow of electrically conductive liquids and providing full fail-to-safe facilities either for contact or no contact with the liquid was demonstrated by Lancashire Dynamo. The equipment operates in liquids having electrical resistances of up to 500,000 ohms, which covers water and most chemicals but not oils. (For oils and explosive liquids the company manufacture a transistorised level control unit.) Either single- or two-level control can be achieved by the same control unit by altering the probe linkage situated within the unit. Positive operation under all circumstances is claimed, as the unit contains no moving parts in contact with the liquid and also because the control sensitivity can be adjusted to the resistance of the liquid. **Lancashire Dynamo Group, Trafford Park, Manchester, 17.**

BCE 7717 for further information

Motor Control Cubicles

Varilectric Ltd. displayed examples of their wide range of motor control cubicles and remote-control stations for use in many sectors of industry. Our illustration shows one of a number of control boards supplied to the Northern Ireland plant of Chemstrand Ltd. Motor starter units are normally mounted in standard 9 in. × 18 in. cases. However, when the size of the contactor and overloads make this arrangement impossible, the starter is mounted in a separate case and controlled locally by a switch mounted adjacent to



the starter. The switch is provided with full mechanical interlock with the starter door, thus preventing access to either the starter or the switch while the switch is in the "on" position. The Varilectric motor control centres are so designed as to give control of a large number of motors and manual sequences from one central point. Each control centre is equipped with all specified push-buttons, pilot lights, instru-

4 YEAR TEST PROVES

THERMOVYL FILTER CLOTHS

LAST LONGER THAN ANY OTHER FILTER CLOTHS

AT THE RHOVYL FACTORY AT TRONVILLE-EN-BARROIS (MEUSE) FRANCE, SAMPLE THERMOVYL FILTER CLOTHS HAVE BEEN KEPT IMMERSED IN THE FOLLOWING CHEMICAL SOLUTIONS FOR FOUR YEARS WITHOUT ANY DETERIORATION.

Concentrated nitric acid
Bleaching fluid (47° chlorometric)
Caustic soda 36° Be
Caustic potash 50%
Sulphuric acid 66° Be
Aqua regia

OUTSTANDING ADVANTAGES OF THERMOVYL 100% P.V.C. FILTER FABRIC.

(A) CHEMICAL RESISTANCE

(a) Inorganic Chemicals
(acids, alkalis and oxidising agents)
Thermovyl fabrics are unaffected by almost the whole range of inorganic chemicals—including concentrated acids and alkalis and reducing and oxidising agents.
Thermovyl filter cloths resist the destructive action of a wider range of chemicals than any other fabric. Thermovyl is the only filter cloth that keeps its strength for at least four years when exposed to highly corrosive acids and alkalis.

(b) Organic Solvents
Although Thermovyl fibre is resistant to a good proportion of these (e.g. alcohols, ethers, and petroleum derivatives) it is swollen, over a certain temperature, by others such as toluene, trichlorethylene, acetone, carbon disulphide, etc.

(B) INSENSITIVE TO WATER
Thermovyl is insensitive to water and to almost all aqueous solutions. It does not therefore swell in water, lose its flexibility or change in dimension. The fibre's mechanical properties (strength, elasticity and extension of break) are exactly the same in a wet or dry state.

(C) RESISTANT TO ATMOSPHERIC CONDITIONS
Thermovyl does not rot or mildew and is immune to bacteriological damage.

(D) NON-INFLAMMABLE
Thermovyl is non-inflammable. This is an inherent property of the fibre.

(E) EASY TO MAINTAIN
Apart from their much longer working life—Thermovyl filter cloths are readily washable. The filter deposits are removed with products normally harmful to other fibres. The whole cleaning operation can therefore be easily carried out without removing the cloth from the filter. Filtration methods can also be simplified because rotting is eliminated and costly dismantling, washing and drying procedures are avoided. In any case—the fact that Thermovyl does not swell in aqueous solutions delays considerably the blockage of the cloth by filtrate accumulation.

USES
Thermovyl cloths allow the filtration of highly corrosive acids and alkalis, and only in very rare cases does any inorganic chemical cause damage. In the case of organic chemicals it is advisable to carry out tests prior to general use, since swelling can sometimes be caused. In such cases the manufacturers can supply more detailed information.
The filtration of gases is made easier by the tendency of P.V.C. materials —such as Thermovyl—to develop electrostatic charges which act like a magnet in attracting particles suspended in the gas. The fabric is not affected by the humidity of the filtered gas because Thermovyl does not swell in water.
Extremely fine particles can be filtered from either liquid or gaseous media by the use of pre-shrunk fabric. The all-round chemical resistance of P.V.C. fibres sometimes permits a considerable simplification of processing. For example, a precipitate from an alkali medium can be neutralised directly by acid on the filter itself. Thermovyl is only one form of the Rhovyl P.V.C. fibre. Other Rhovyl P.V.C. fibres with different reactions to heat can be used to solve particular filtration problems.

The following are suppliers of filter cloths in 100% Thermovyl P.V.C. fibre:

FOTHERGILL & HARVEY LTD.,
Harvester House, Peter St.,
Manchester 2.

JAMES KENYON & SON LTD.,
Roach Bank Mills, Bury,
Lancashire.

PORRITT, BROTHER & AUSTIN LTD.,
Broadway Mills, Haslingden, Lancs.

For further information, contact: **COMBINED ENGLISH MILLS (SPINNERS) LTD., GLOUCESTER ST., ATHERTON, LANCS. TEL: ATHERTON 351**

BCE 7653 for further information

Thermovyl FILTER CLOTHS

ments, etc., together with a mimic diagram. The wiring from the equipment is taken to a terminal chamber, each terminal being clearly designated to conform with its respective terminal in the motor control cubicle. Varilectric Ltd. are also stated to be developing a new low-tension air circuit breaker. **Varilectric Ltd., No. 8 Building, 10 Melon Road, London, S.E.15.**

BCE 7718 for further information

Mining Motors

Newman Industries displayed a Class B insulated mining motor with a water jacket round the stator and 5 gal. of cooling water flowing a min. so that the temperature rise does not exceed 55°C, which, the company states, is well within even Class A limits. This motor is continuously rated at 75 hp, 1470 rpm, on a 50-cycle, three-phase supply and is said to equal in performance, while in cross-section taking up only half the area, of the conventional design of motor. Inverted induction motors and alternators of compact design were also exhibited by this company. The motor is a pulley with the rotating stator designed to take the electrostatic belt load. Similarly, the inverted alternator acts as the pulley at the other end of the belt and this is used to produce the power for an ionising source and an electronic control system. The motor is a four-pole, three-phase, squirrel-cage machine developing 10 hp continuous rating at 1470 rpm on a 50-cycle supply. The alternator comprises three separate inverted permanent-magnet type, single-phase alternators, each continuously rated at 115 volts, 500 VA, 0.8 PF, 194 cycles when running at 1460 rpm. **Newman Industries Ltd., Yate, Bristol.**

BCE 7719 for further information

Annunciator Units

A system of alarm indication which has been designed to give instant and clear indication if a process or part of a process develops a fault was introduced at the exhibition by Londex Ltd. The Annunciator Units, as they are termed, work in conjunction with measuring equipments such as contact thermometers, contact gauges, pressure switches, etc. The system is so designed that it can be extended easily without requiring alterations to any existing equipment. Comprising a master unit and any desired number of signalling units, the system contains a flasher, a bell or klaxon and a "supply healthy" lamp. Under normal conditions the control contact (for example, a pressure switch) is open and a green lamp on a signal unit is lit. When a fault develops (pressure contact switch closes) the first armature on a special relay operates contacts which cause the green light to extinguish, a red light to start flashing and a klaxon on the master unit to sound. When the alarm has been noticed and a cancel button pressed, the klaxon is silenced and at the same time a red lamp is made to burn steadily. These conditions prevail until the alarm condition is returned to normal (the pressure contact switch reopened). When this occurs the red lamp is extinguished and the green lamp re-lit. The operation with the signal unit controlled by a normally closed alarm contact is similar. **Londex Ltd., Anerley Works, 207 Anerley Road, London, S.E.20.**

BCE 7720 for further information

New Publications

A bulletin "Vandike Emulsions" reviews the range of Vandike emulsions now available and outlines their uses. The emulsions are stable dispersions of fine particles of thermoplastic resin in water. In most cases the resin is polyvinyl acetate. The emulsions can be diluted with water; storage vessels and equipment used with these emulsions can be cleaned easily with water immediately after use. They do not contain any volatile organic solvents and are non-toxic and non-inflammable. These emulsions dry by evaporation or by absorption of the water into the substrate to leave clear, colourless, water-insoluble resin films. **British Oxygen Chemicals Ltd., Cleveland Row, London, S.W.1.**

BCE 7721 for further information

A brochure ("Corrosion Surveys with Particular Reference to Foundation Engineering") has been issued to explain how a corrosion survey is carried out as part of a complete site investigation with the object of assessing the corrosivity of an environment towards the materials to be used in the construction of the foundation. The survey usually includes a general appraisal of the geology, pedology, drainage and local peculiarities such as the presence of chemical waste and stray electric currents in the ground. **Soil Mechanics Ltd., Old Church Street, London, S.W.3.**

BCE 7722 for further information

The Carlton Weathering Test Station provides exposure and laboratory facilities for testing specimens and their performance under normal conditions. Where extremes of exposure or other conditions not possible at this station are required, it is arranged for information to be secured from other testing sites throughout the world.

A paper ("Flotation in Paints—A Suggested Mechanism") draws attention to some of the factors affecting flotation. It explains why "cures" sometimes work and sometimes fail. It points out how changes in atmospheric conditions over which neither paint manufacturer nor paint user has any control may cause flotation to appear or disappear.

Anatase and rutile-type titanium dioxides are both used in the production of white and pastel shades of rubber. Generally, manufacturers appear to prefer anatase pigments, probably because they have a more neutral tone than the rutile types, which are slightly cream/white. However, a technical note ("Pigmentation of Rubber with Titanium Dioxide") shows that for certain applications, particularly where colour stability and resistance to weathering are desirable, the rutile types have a decided advantage. For equivalent covering power a lower loading of a rutile-type pigment can be employed to give a compound of lower cost. Copies of the three publications described above are obtainable from **British Titan Products Co. Ltd., Stratton Street, London, W.1.**

BCE 7723 for further information

A beautifully produced brochure ("Le Chlore/Cl_2") with an attractively designed cover lists the history, manufacturing techniques, properties and general characteristics of chlorine, then goes to packaging, stores and a selection of the wide range of uses. **Solvay & Cie, Rue Prince Albert, 33, Bruxelles, Belgium.**

BCE 7724 for further information

A supplement ("Produits Nouvellement mis sur le Marche") to the basic catalogue of Solvay lists hydrogen peroxide, sodium perborate, a high-density polyethylene, copolymers of vinylidene chloride and an anti-dust agent for coal. All products are detailed with specifications and recommendations for storage. **Solvay & Cie, Rue Prince Albert, 33, Bruxelles, Belgium.**

BCE 7725 for further information

A brief history of the Solvay company ("La Chimie au Service de L'Industrie"), artistically produced and generously illustrated, shows the location of their various plants and is accompanied by other brochures. **Solvay & Cie, Rue Prince Albert, 33, Bruxelles, Belgium.**

BCE 7726 for further information

It is just 100 years ago since Fraser & Chalmers began to make mining and metallurgical machinery. The British company of Fraser & Chalmers Ltd. has long been absorbed into the General Electric Co. Ltd. of England, but maintains its fine engineering traditions. To mark this occasion, a brochure ("A Century of Service to the Mining Industry") has been produced describing the extensive range of equipment designed and manufactured at Erith. It is intended to show how they are well qualified to carry out the engineering of fully comprehensive schemes from their inception. The brochure refers to screens and feeders, several types of crusher, machines for concentration of minerals, ball and rod mills and materials handling plant. **General Electric Co. Ltd., Erith, Kent.**

BCE 7727 for further Information

A new bimonthly has joined the 1500 house journals already circulating in the U.K. It is called "The Double Bond" and is read by employees of British Hydrocarbon Chemicals Ltd and subsidiaries at Grangemouth and London office. The publishers are Newman Neame Ltd. **British Hydrocarbon Chemicals Ltd., Devonshire House, Mayfair Place, London, W.1.**

BCE 7728 for further information

COCHRAN

PRESSURE VESSELS WITH A NAME

Pressure vessels by Cochran — built to all standards and specifications in sizes up to 14′ 0″ DIA. and up to 100 tons in weight.

Send us your enquiries — you will find our prices are competitive.

Cochran & Co., Annan Ltd., Annan, Dumfriesshire, Scotland. Annan 111

and at 34, Victoria St., London, S.W.1.

ABBey 4441

World of Chemical Engineering

I.C.I.'s Capital Expenditure

In 1959 I.C.I. spent £32.2 million on construction projects in the United Kingdom, compared with £45.3 million in 1958 and £50.6 million in 1957. During 1959 £22 million was sanctioned for new projects, and the amount of outstanding capital expenditure which had been sanctioned but not yet spent was reduced from £49.8 million to £39.6 million. The rate of capital expenditure in the earlier part of 1960 will, it is stated, again be less than in the preceding year, but is expected to be reversed towards the end of the year. The largest projects sanctioned in 1959 were a polypropylene plant at Wilton, and a "Melinex" film plant at Dumfries, for the Plastics Division; a plant for polyurethane chemicals at Fleetwood for the Dyestuffs Division; and large extensions to the solvent plants and the plants for methyl methacrylate monomer for the General Chemicals Division. Towards the end of the year, sanction was given to a project for the manufacture of ethylene oxide and glycol at a cost of £5 million by the Heavy Organic Chemicals Division at Severnside; this will be the first plant to be erected on this 1000-acre site on the River Severn near Thornbury, Gloucestershire, which I.C.I. hopes to develop on similar lines to its Wilton works. A second project, to cost upwards of £10 million—a new ammonia plant with a capacity of 10,000 tons a year—has also recently been announced. This, with its associated plants to make urea and fertilisers, is expected to be in production by 1963. Plans are in hand by the Nobel Division for further concentration of explosives manufacture and the introduction of new and more efficient machines and processes.

Steel Companies Link-up

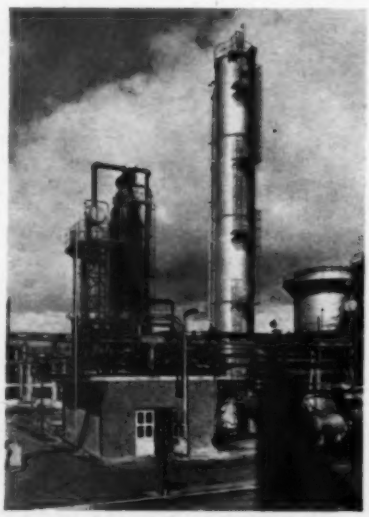
A new company, British Ore Investment Corporation Ltd. (B.O.I.C.), with a share capital of £5 million, has been formed by nine of the principal British steelmaking companies using imported ore and by British Steel Corporation Ltd., an investment-holding company associated with the British Iron and Steel Federation. The main object of B.O.I.C. is to hold investments in overseas ore-mining companies—a function formerly undertaken for the British steel industry by the British Steel Corporation alone. The principal shareholders in B.O.I.C. are: British Steel Corporation; The Steel Company of Wales Ltd.; Colvilles Ltd.; South Durham Steel & Iron Co.; Dorman Long (Steel) Ltd.; John Summers & Sons Ltd.; Richard Thomas & Baldwins Ltd.; Consett Iron Co. Ltd.; Guest Keen Iron & Steel Co. Ltd.; and The United Steel Companies Ltd. Among other investments, B.O.I.C. has taken over the British Steel Corporation's 20% interest in Société des Mines de Fer de Mauritanie (MIFERMA), a £60-million project in French West Africa whose capital, equivalent to about £19 million, is being subscribed together with French, Italian and German interests. The ultimate intention of MIFERMA is to produce six million tons of iron ore a year. The ore will be transported on a railway, to be specially constructed, over a distance of about 400 miles to the port to be built near Port Etienne in Mauritania. B.O.I.C. has also taken over the 30½% British participation in Compagnie Minière de Conakry, a company mining ore in the Republic of Guinea.

Tanker Service to the Continent

Marchon Products Ltd. are developing direct delivery by road tankers of liquid chemical intermediates in bulk from Whitehaven to continental destinations. The continental ferry service operating from Felixstowe to Rotterdam, with regular weekly sailings, is proving a most efficient and economical method of effecting deliveries of large quantities of liquid in bulk to Germany, making it possible to deliver direct into the customers' premises within four to five days of the product leaving the Marchon plant in Whitehaven. This door-to-door service, planned essentially to meet the demands of large bulk liquid consumers with their own storage tank installations, is operated jointly by Bulk Liquid Transport Ltd. of Gildersome, Leeds, and James Fisher & Sons Ltd., ship-owners, Barrow-in-Furness. It is hoped eventually to extend the service to Italy, Austria and Switzerland.

S.E.G.B.'s Plant Completed in under Eight Months

The benzole recovery and desulphurising plant at the Isle of Grain works of the South Eastern Gas Board was completed in just under eight months, the order having been received by W. C. Holmes & Co. Ltd. on March 26, 1959, and the plant commissioned on November 20, 1959. This plant, which has a daily capacity of 16 million cu. ft of gas, operates on gas produced by the Segas process and is installed immediately after the dry purification plant. The circulation system uses vacuum distillation of the oil, which has the merit of maintaining the circulating oil in good condition more or less indefinitely. Another advantage of this type of plant is that it is extremely economical in steam. One interesting feature is the inclusion of a naphthalene stripping section in the main vacuum still which deals with the oil from a naphthalene washer on another part of the plant. A further feature is the use of a steam jet vacuum pump as a stand-by to the main rotary vacuum pump. The plant was designed and constructed by Holmes' Chemical Engineering Division.



The benzole recovery and desulphurising plant installed at the Isle of Grain works of the South Eastern Gas Board.

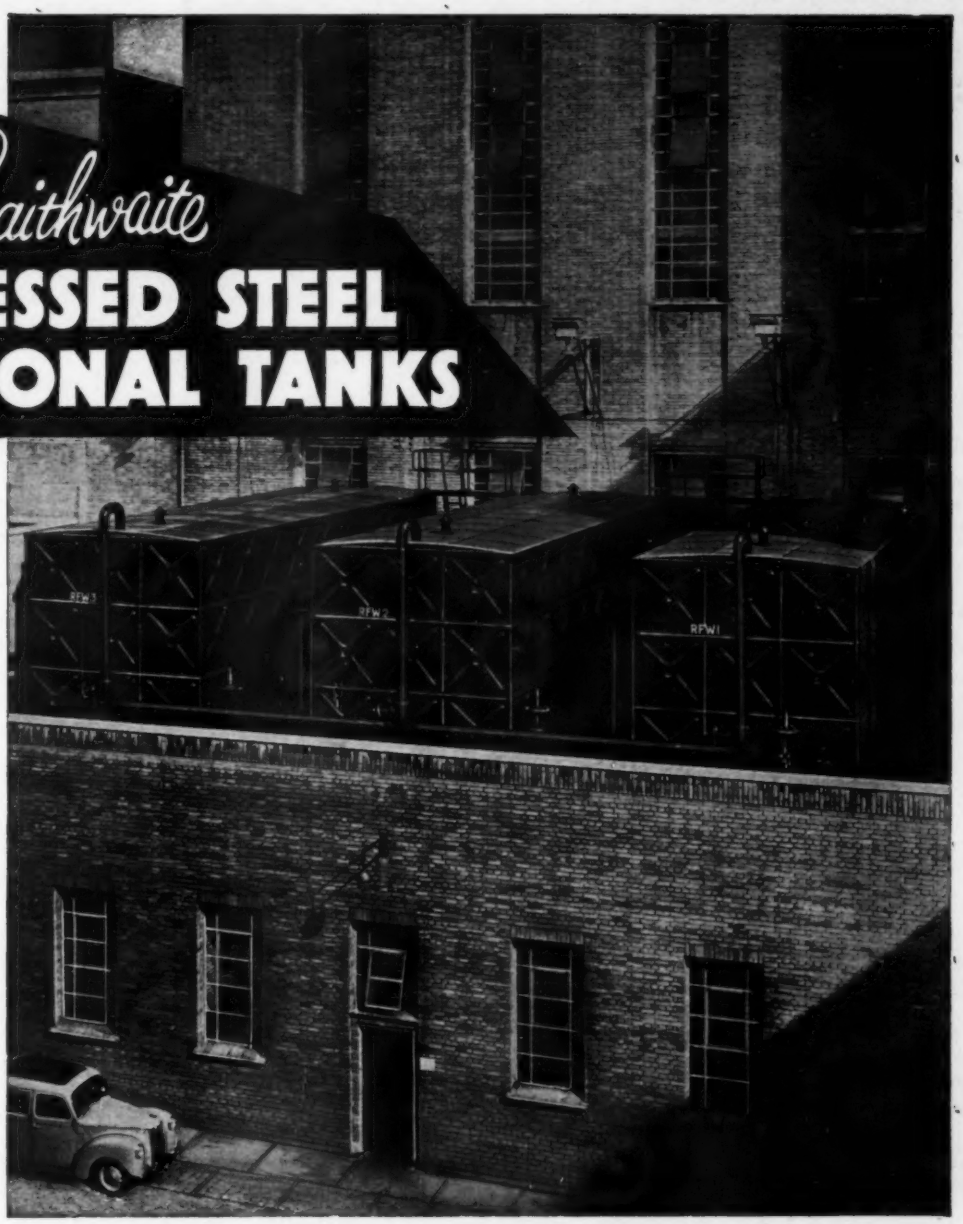
News Briefs

The first set of purifiers to be specifically designed to take advantage of the principle of rapid rotation (British Patent Application Nos. 10434/58, 26587/58, 36896/58) was commissioned in December, 1959, at the Southampton works of the Southern Gas Board. These purifiers, which were installed for the purpose of removing hydrogen sulphide from refinery gases at the inlet of the reforming plant, were designed and constructed by the Chemical Engineering Division of W. C. Holmes & Co. Ltd. to the order of Humphreys & Glasgow Ltd.

Head Wrightson Processes Ltd., a subsidiary of Head Wrightson & Co. Ltd., have been supplying furnaces to the petroleum and chemical industries for a number of years, and to meet their expanding operations in this field they have formed an Industrial Furnace Division at their London offices, 20-24 Old Street, E.C.1. This development, it is said, will strengthen the services at present offered to these industries both in this country and abroad.

The British Association of Corrosion Engineers (97 Old Brompton Road, London, S.W.7) has been elected a member of the European Federation of Corrosion. Membership of the Federation is restricted to non-profit-making European technical and scientific societies whose activities are connected with the field of corrosion or the protection of materials. The B.A.C.E. was formed in 1959 to promote the dissemination of technical information about corrosion matters; to develop the free interchange of information among members; and to promote such educational and other facilities as may be required for the establishment of corrosion engineering as a recognised profession.

Bradford Institute of Technology,



Braithwaite PRESSED STEEL SECTIONAL TANKS

Braithwaite Pressed Steel Tanks with external flanges throughout comply with British Standard 1564: 1949. The sectional method of construction enables tanks with an unlimited range of capacities to be provided. Suitable for the storage of most liquids and viscous substances, they can be economically transported and erected in positions inaccessible to other forms of construction. They can also be increased in size when additional capacity is required. Illustrated brochure will be sent on application.

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Bradford 7, are to hold a special short course on "The Uses of Plastics and Polymers in Chemical Engineering". This will be held on June 17 and 18, 1960. The subjects to be dealt with are: "The Nature of Plastics and Polymers"; "Properties of Plastics and Polymers in Relation to their Uses in Chemical Plant and Processes"; "The Uses of Plastics in Chemical Plant"; "Some Uses of Natural and Synthetic Rubbers in Chemical Plant"; and "The Uses of Glass Reinforced Plastics in Chemical Plant".

In the May issue, p. 351, the opening date of the Warren Spring Laboratory should have been given as "June 29, 1959".

The American Institute of Chemical Engineers will hold a four-day joint meeting with the Instituto Mexicano de Inginieros Quimicos at the Hotel Del Prado, Mexico City, June 19 to 22. It will be the first joint meeting of the two societies and the occasion will be the first time in the 52-year history of the Institute that it has met outside the continental United States, except for Canadian meetings.

Overseas News

Australia's first major lubricating oil refinery is to be built at Kurnell, near Sydney, at an estimated cost of between £A11 million and £A13 million. The capital cost will come from United States and Australian interests on a 50-50 basis. Ampol will provide 25%, H.D. Sleigh Ltd. 25%, and the remaining 50% by the U.S. Caltex Oil & Co. Construction will begin almost immediately on 300 acres of land at Kurnell.

Plans for the construction of a new plant for the production of propylene oxide and derivatives have been announced by the Union Carbide Corporation. The new plant will be constructed and operated by S.p.A. Celene, a company formed in 1957 and jointly owned by Union Carbide and Societa Edison. The plant will have an initial capacity of 25 million lb. of propylene oxide annually. The new plant will be located at Priolo, Sicily, adjacent to Celene's other production facilities. The basic raw materials for the new expansion will be obtained from the adjoining plant of SINCAT.

A further announcement from Union Carbide gives details of the production of 1 lb. of scandium, an extremely rare metal. This is stated to be the first time that such a "large" quantity of scandium has ever existed in one place at one time. The accomplishment also marks the completion of the first of two contracts with Materials Laboratory, Air Research and Development Command and the Air Material Command of the United States Air Force at Wright Air Development Centre. This contract called for 1 lb. of scandium of at least 99% purity. The material is in the form of two discs of scandium about 3¼ in. in diam. and 3¼ in. thick, whose 99% purity met the United States Air Force contract specifications. The cost of completing this contract was shared partly by Union Carbide.

Scandium is believed to have some unique properties. It has a density comparable to aluminium, but at the same time has a relatively high melting point of 1550°C, or about 2½ times the melting temperature of aluminium. The second contract, already under way, calls for an analysis of the material by Union Carbide to study its physical, chemical and mechanical properties.

Shell Oil Co. of Canada Ltd. is considering the purchase of an industrial site south-east of Calgary as a possible location for a refinery for the manufacture of automotive and domestic fuels for the Alberta market. An option on the 310-acre tract of land was negotiated some time ago through J. C. Leslie & Co Ltd. Shell's present manufacturing facilities include a refinery at Montreal East and one at Burnaby, B.C. The company also has a chemical plant adjacent to its Montreal East refinery and a gas processing plant at Jumping Pound, Alberta.

Sueddeutsche Kalkstickstoff-Werke, of Trostberg, Bavaria, have recently put into operation a 48-ton/day rotating furnace process for the production of calcium cyanamide by exothermic nitrogenation, which is new in that it utilises calcium carbide in a fine state of subdivision. Previous processes for the manufacture of calcium cyanamide by the nitrogenation of calcium carbide have used a particle size of the latter material of up to 2.0 mm. As nitrogenation is a surface reaction, the process efficiency is greatly influenced by particle size, and the process developed by Sueddeutsche Kalkstickstoff is based on a calcium carbide particle size of less than 0.2 mm, resulting in a better yield at lower power consumption. A further interesting feature of the Sueddeutsche process is the use of a horizontally rotating furnace as against the rotary kiln which is normally used. The rotary furnace was developed by Fellner & Niegler of Frankfurt.

Contracts

Baker Perkins Ltd., of Peterborough, have secured a contract worth nearly £¼ million for pneumatic handling and mixing equipment which will be installed at Shell Chemical Co. Ltd.'s new polyolefins plant at Carrington. The main contractors for the plant are Matthew Hall & Co. Ltd.

Orders worth some £39,000 have been received by Firth Cleveland Instruments Ltd., a member of the Firth Cleveland Group, from the Shell International Petroleum Co. Ltd. on behalf of Shell Refining Co. Ltd. for Gilbarco-Firth Cleveland automatic tank contents gauges to be fitted to 51 petroleum storage tanks. This will be the first major installation of this equipment in the U.K. The tanks are located at the South, Tranmere and Hill Sites at Shell's Stanlow (Cheshire) refinery and at the Shellhaven refinery in Essex.

W. C. Holmes & Co. Ltd., Huddersfield, have received an order valued at some £31,000 for the installation of a complete briquetting plant at the Kingston upon Thames "B" Power Station of the Central Electricity Generating Board. The plant, which has been designed in collaboration with Neldco Processes Ltd. and Conreur Ledent et Cie of Raismes, France, who will supply the press, is scheduled to be in operation before the end of 1960.

British Hydrocarbon Chemicals Ltd. have announced that contracts have now been placed with the following firms for the construction of three new petroleum chemical plants which constitute a £5-million expansion programme at the company's Grangemouth, Stirlingshire, site. The contracts are for a new methanol plant to Chemical Construction (G.B.) Ltd.; for a new ethylene dichloride plant to The Lummus Co. Ltd.; and for a new butadiene plant to the Fluor Engineering & Construction Co. Ltd.

People in the News

Mr. G. F. Ashford has been appointed deputy chairman of the Chemical Group, The Distillers Co. Ltd. **Mr. J. M. Rimington**, managing director of the Chemical Division, who retired on April 1 for health reasons after 30 years' service, was succeeded by **Mr. J. H. Dunn. Mr. J. S. Hunter** succeeded Mr. Dunn as assistant managing director (commercial) of the Chemical Division.

Mr. I. A. Bailey has been appointed deputy chairman of The Mond Nickel Co. Ltd. and of Henry Wiggin & Co. Ltd., and **Mr. E. Vaughan** has been appointed a director of both companies.

At his own request, **Sir William Garrett**, chairman of the Association of British Chemical Manufacturers and a director of Metal Industries Ltd., relinquished on April 1 his executive responsibilities with Monsanto Chemicals Ltd. in order to devote more time to his other interests. He will continue as a member of the board. Among his other executive activities at Monsanto, Sir William held the position of personnel director. These duties will now be assumed by **Mr. N. F. Patterson**, director in charge of engineering and purchasing.

Dr. R. L. P. Berry, beryllium project manager since 1958, has been appointed to the board of I.C.I. Metals Division. He has also been appointed to the delegate boards of two I.C.I. subsidiary companies, Marston Excelsior Ltd. and Lightning Fasteners Ltd.

Industrial Films

A new 16-mm sound/colour film, **Accent on Mechanical Handling**, had its first showing in London during March. Based upon sequences taken at recent Mechanical Handling Exhibitions, the film depicts one or more examples of each of the various classes of mechanical handling equipment, and the commentary by Bob Danvers Walker describes the classes of goods they are designed to handle.

Action shots are provided of many exhibits in operation, ranging from fork-lift trucks and conveyors to electronic control equipment and aerial ropeways. The film, a graphic tribute to the ingenuity and skill of British engineers in their constant efforts to save time, cost and labour in every industry, is intended for world-wide distribution. It is available free on loan from *Mechanical Handling*, Dorset House, Stamford Street, London, S.E.1.